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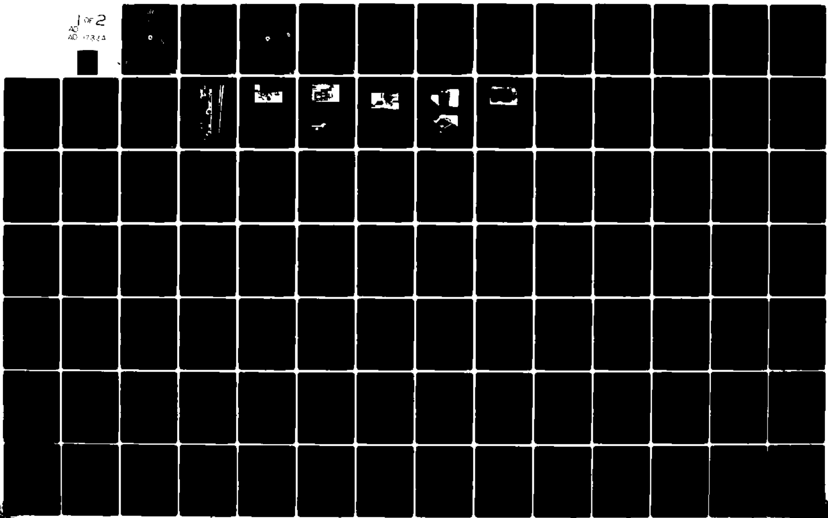

Report No. FAA-AAS-80-1

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N. C. Wenck
P. D. Josephson
J. B. Erdmann

E. A. Hickok and Associates, Inc.
545 Indian Mound
Wayzata, Minnesota 55391

DECEMBER 1980

FINAL REPORT

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office Of Airport Standards
Washington, D. C. 20591

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
19 FAA-AAS-80-1	AD-A097 334	

4. Title and Subtitle	5. Report Date
6 NATIONAL RUNWAY FRICTION MEASUREMENT PROGRAM, Final Report	
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
10 J. R. MacLennan, N. C. Wenck, P. D. Josephson, J. B. Erdmann	11 Dec
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
E. A. Hickok and Associates, Inc. 545 Indian Mound Wayzata MN 55391 Nov	12 120
	11. Contract or Grant No.
	15 DOT-FA78WA-4242
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Office of Airport Standards 800 Independence Avenue Southwest Washington D.C. 20591	9 Final Report. Sep[redacted]78 [redacted] Dec[redacted]80
15. Supplementary Notes	14. Sponsoring Agency Code
Prepared in cooperation with: Becher-Hoppe Engineers, Inc., Bison Instruments, Inc. University of Minnesota	AAS-1

16. Abstract

Measurements of runway friction, pavement surface conditions and engineering data for 491 runways at 268 U.S. airports are used for statistical analysis to develop guidance materials to insure the design and maintenance of nonslippery surfaces at United States airports. Friction values are analyzed as they relate to pavement type, texture depth, grooving, and rubber accumulation. The basic concepts of Advisory Circular 150/5320-12 are supported by the data. Corrective maintenance action is recommended for runways with friction values less than the recommended value of 0.50.

17. Key Words		18. Distribution Statement
Asphalt Pavement	Rubber Accumulation	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22150
Concrete Pavement	Surface Treatment	
Friction	Texture	
Grooves		
Mu-Meter		
Pavement Condition Survey		

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	120	

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PREFACE

The authors wish to acknowledge the support of the Federal Aviation Administration in the performance of the National Runway Friction Measurement Program. The assistance and direction of Mr. Thomas Morrow, Technical Officer for the project, is appreciated, as well as the help of Mr. Charles Williams, Contracting Officer and Mr. Robert Kopp, Contract Specialist. Special thanks are due Messrs. Robert Aaronson, William Vitale, Leonard Mudd, Ed Aikman, and John Rice for their encouragement and direction as the program was implemented and concluded.

Appreciation is also extended to the numerous other FAA personnel who provided suggestions during the project, including Messrs. Quentin Taylor, Joseph Foster, Robert Endres, Merritt O. Chance, John Kal, Luther Falls and Penfield Tate.

The cooperation of FAA regional personnel, including Messrs. Mel Rosen, Eastern Region; Murli Hasrajani, Great Lakes Region; William Carson, Central Region; Will Koliha, Rocky Mountain Region; George Paul, Western Region; Bill Cronan, New England Region; Charles Glasgow, Northwest Region; Blair Harvey, Southwest Region; and Don Morgan, Southern Region is also greatly appreciated. The airport managers and staff of the 268 airports in the program were very helpful, and are thanked for their cooperation.

The firm of E. A. Hickok and Associates appreciates the cooperation received from the Consultant Team, including Mr. Francis Schwartz and Mr. Richard Sherrard of Bison Instruments, Inc.; Dr. Eugene Skok, Jr. of the Civil and Mineral Engineering Department, University of Minnesota; Bruce Watson, consulting meteorologist; Dr. Frank Martin, retired director of the Statistical Center, University of Minnesota; and Mr. Archie E. Becher, Jr., Mr. Al Fawley, Mr. Gene Meyer, and Mr. Richard Decker of Becher-Hoppe Engineers, Inc.

Also to be acknowledged are the personnel within the firm of E. A. Hickok and Associates who have put much time and effort into implementing the program and assembling the final report. The personnel from the firm of E. A. Hickok and Associates associated with the project include Mr. John MacLennan, Mr. Norman Wenck, Mr. Paul Josephson, Ms. Elizabeth Johnson, Dr. Daniel Knuth, Mr. John Erdmann, Mr. Dale Brintnall, Mr. Kirk Johnson, Ms. Mary McBride, Ms. Doris Minnerath, Mr. Steven Monson, Mr. Brian Pluemer, Mr. Clifford Reep, Mr. Greg Saunders, Mr. Jim Wenzel, Mr. Steven Wieber, and Mr. Mark Winson. Team members Mr. Archie C. Becher, Mr. Robert Nichol, Mr. Dennis Ouderkirk, and Mr. Randy VanNatta were from the firm of Becher-Hoppe Engineers, Inc.

The suggestions, comments and guidance provided by the personnel from the aviation community have been greatly appreciated, and it is hoped that the information provided in this report will be useful to them.

EXECUTIVE SUMMARY

The Federal Aviation Administration contracted with the firm of E. A. Hickok and Associates to perform the National Runway Friction Measurement Program as described in Contract No. DOT-FA78WA-4242 dated September 29, 1978. The program included runway friction measurements and evaluation of pavement surface conditions on 491 runways at 268 airports that have at least one ILS runway serving scheduled turbo-jet operations throughout the 48 contiguous United States. The data were used to develop guidance materials to help insure the design and maintenance of nonslippery surfaces at United States airports.

The program consisted of two phases. The specific purposes of Phase I were to develop survey procedures and evaluate the performance of t... specified equipment. The results of Phase I are contained in the National Runway Friction Measurement Program Phase I Summary Report, dated June 26, 1979.

The primary purpose of the data gathering process was the collection of pavement surface friction measurements. Friction measurements were performed with Mu-Meters equipped with self-watering systems. The Mu-Meter evaluates the side-force friction between measuring tires and pavement surface. Measurements were made with a controlled water depth of 1.0 millimeter (0.04 inches) at 40 miles per hour. The friction is reported as wet Mu value, which has a theoretical range from 0 to 100. Other field procedures included a pavement condition survey and an engineering data inventory for each runway. Six survey teams accomplished the data collection.

Quality control was essential to the data collection process. Each survey team evaluated the collected data in the field. Data anomalies were investigated and retesting was performed if necessary. Portable computer terminals were used for field data entry so that survey results were immediately available to the contractor's home office and the FAA project office. Accuracy of data transfer was constantly evaluated at the home office. Senior personnel performed field quality control to assure consistency in data collection procedures.

After each testing, a brief Airport Survey Report was produced to provide rapid feedback to airport management. At the conclusion of all field work, an engineering evaluation was performed on the data as a whole using statistical and analytical techniques.

The data analysis required a computerized data base and was performed with a nationally vended computerized statistical package. The primary methods employed were multiple regression and correlation. Residual analysis was employed in reviewing the outcome of regression runs and led to identification of unique circumstances, thereby allowing verification of the data prior to drawing general conclusions.

For the engineering evaluation, surface friction and other pavement surface conditions were averaged over 500-foot long runway segments. Including all runways and test dates, the data base contained over 42,000 such segments. Statistical analysis was confined to some 29,000 uniform segments. Of the 491 runways tested, 122 (24.8%) had wet Mu values less than 50 on at least one 500-foot segment on their final test. However, only 1900 (4.5%) of the 42,000 segments had wet Mu values less than 50. Of the 122 runways with low segments, 64 runways (52.5%) had wet Mu values less than 50 for less than 1000 feet.

Other data analyzed included some 5,630 spot measurements of texture depth and data obtained from airport management on runway usage, construction and rubber removal. Runway friction was evaluated in relation to pavement type, texture depth, grooving, rubber accumulation, aircraft landings and rubber removal.

The primary conclusions reached by the engineering evaluation are listed below:

1. Rubber accumulation on runway pavements profoundly affects surface friction. These effects have been quantified for various pavement types and range from 1.6 to 6.9 wet Mu value decrease per unit increase in rubber accumulation rating.

2. Rubber removal improves runway surface friction characteristics.

3. Saw-cut grooving improves runway surface friction. The friction enhancement due to grooving is greater in areas of rubber accumulation than in uncontaminated areas for most pavement types.

4. For low-use runways, a reasonable basis for comparing and ranking the surface friction characteristics of various pavement types is provided by mean wet Mu values for uncontaminated areas. (See Table 4 and Figure 9, pp. 17 and 18.)

5. For high-use runways, guidelines have been developed for rubber removal frequency dependent on pavement type and annual landings. (See Figure 19, p. 38.) These guidelines can be used in projecting and comparing annual costs of runway construction, resurfacing or pavement treatment alternatives, as well as in guiding maintenance of existing runways.

6. The Airport Survey Reports produced for each of the 268 airports after each testing provided timely input for airport maintenance purposes.

7. The purpose and objectives of the National Runway Friction Measurement Program were achieved. Mu-Meter measurements and Pavement Condition Survey data obtained in this program have yielded a rational and useful analysis of runway friction.

8. The Mu-Meter is a rapid and effective device for measuring surface friction when operated in accordance with the manufacturer's instructions.

9. A Mu value of 50 or greater has long been generally accepted as providing adequate runway friction under most operating conditions. This program did not disclose data to support any other value. It must be understood that as friction decreases the relative safety decreases, but it is gradual and time-related, that is, when the Mu value decreases from 50 to 49 the pavement does not go from totally adequate to totally inadequate.

The following are selected recommendations resulting from the program:

1. Pavement types having high surface friction, as identified in Figure 9, should be considered in the planning and design of new runway surfaces, particularly for low-use runways.

2. The guidelines for rubber removal frequency, as contained in Figure 19, should be used in planning and design of new runway surfaces and as a maintenance guideline, for high-use runways. Specific scheduling of rubber removal for an existing runway should ultimately be based on direct observation of rubber accumulation and measurement of surface friction.

3. The rating system used in this program for rubber accumulation should be formalized and promulgated for use by airport maintenance personnel.

Additional conclusions and recommendations may be found on pages 49-52.

The draft final report was reviewed by representatives of various segments of the aviation community. The comments from this group were incorporated to the extent possible. As might be expected, due to the diverse interest of this group, there was not unanimity on all matters on which comments were received.

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1. INTRODUCTION

1.1. OBJECTIVES

The Federal Aviation Administration contracted with the firm of E. A. Hickok and Associates to perform the National Runway Friction Measurement Program as described in Contract No. DOT-FA78WA-4242 dated September 29, 1978.

The purpose of the program was to provide a data base and statistical analysis to assist the Federal Aviation Administration in evaluating the engineering criteria in Advisory Circular 150/5320-12, and to develop further guidance materials to insure the design and maintenance of non-slippery pavement surfaces at United States airports. The specific objectives of the program were to:

1. Update, expand and disseminate improved guidance material contained in Advisory Circular 150/5320-12 on runway friction and related airport safety items.

2. Provide airport managers with timely input for fiscal programs.

3. Increase effectiveness of the Airport Development Aid Program (ADAP) by identifying the airport pavement construction methods most effective in providing good friction characteristics.

4. Enhance safety by reducing hydroplaning and improving runway friction characteristics by development of recommendations for improved maintenance and maintenance monitoring practices.

The program consisted of two phases. The specific purposes of Phase I were to develop survey procedures and evaluate the performance of the specified equipment. The results of Phase I are contained in the National Runway Friction Measurement Program Phase I Summary Report, dated June 26, 1979.

1.2 SCOPE OF WORK

The project included runway friction measurements and evaluation of pavement surface conditions on 491 runways at 268 airports that have at least one ILS runway serving scheduled turbo-jet operations throughout the 48 contiguous United States. Table 1 lists the number of airports, runways and surveys in total and by region.

TABLE 1. SCOPE OF WORK

Region	Airports	Runways	Surveys
Central	19	39	118
Eastern	32	62	180
Great Lakes	49	104	298
New England	10	18	48
Northwestern	15	22	61
Rocky Mountain	28	45	118
Southern	56	95	297
Southwestern	33	65	185
Western	26	41	113
Total	268	491	1,418

This report reviews the program and provides conclusions and makes recommendations based upon statistical analyses of the data and accumulated field experience.

2. DISCUSSION

2.1 SCHEDULE AND TRAINING

2.1.1 Schedule

The date and location for each survey conducted throughout the program are listed in Appendix A. Most airports were surveyed three times, with consecutive surveys at least 60 days apart. The voluntary participation of each airport made it possible to collect an extensive data base.

2.1.2 Team Member Rotation

The planned work cycle consisted of 21 consecutive work days followed by 9 consecutive days off. Normally, one team member returned to the same truck while the other rotated to a different truck and equipment at the beginning of each 21-day tour. Rotation was useful for keeping survey procedures consistent throughout the program.

2.1.3 Training

On May 7-11, 1979, a comprehensive classroom and field training course was conducted at Dulles International Airport in Washington, D.C. Engineers, scientists and engineering technicians were trained in Mu-Meter operation and maintenance, and pavement evaluation parameters. Subsequent training meetings were held bimonthly to provide continuing instruction and quality control. On-the-job training was also provided by qualified, trained team members and visiting quality control personnel.

2.2 EQUIPMENT

2.2.1 Tow Vehicles

Supercab pick-up trucks were used as tow vehicles. The vehicles were equipped with a 60 amp alternator, heavy duty batteries, automatic speed control, a rotating beacon, exterior flood lights, a ground control radio with exterior speakers, a 340 gallon water tank, and other water pumping equipment. A tow vehicle is shown in Figure 1.

2.2.2 Friction Test Equipment

A Mu-Meter with a MK 3 recorder was the device used for measuring pavement side-force friction. Attached to the triangular frame were two side wheels, which measured friction, and one back wheel, which measured distance and drove the strip chart. A close-up of the Mu-Meter is shown in Figure 2.

FIGURE 1. WET FRICTION TEST

FIGURE 2. MU-METER

When in test position, the two friction measuring wheels were set at a nominal included angle of 15 degrees (7½ degrees each wheel). The Mu-Meter measured the side slip force on these two wheels, which is directly proportional to the friction between the measuring tires and the pavement surface. The Mu-Meter measures the force perpendicular to the direction of travel and is therefore insensitive to variations in bearing friction and rolling resistance. Because it is towed, it will self-align and equalize the forces on both wheels. The Mu-Meter was equipped with a self-watering system, which distributed a controlled water depth of 1.0 mm (0.04 in.) in front of each friction measuring wheel.

An automatic printout unit mounted inside the tow vehicle provided a display of the data coming from the Mu-Meter. This device calculated the average friction for each 500 feet traversed, displayed it visually and printed a tape for the permanent record. The automatic printout unit is shown in Figure 3.

Radiant temperature thermometers were used to determine the pavement surface temperature for each friction run.

2.2.3 <u>Pavement Condition Survey Equipment</u>

A Transwave distance measuring computer was used to measure runway location. The computer and display were mounted in the vehicle cab, as shown in Figure 3. The Transwave was equipped with a 30 register memory which allowed rubber accumulation values at different locations along the runway to be stored for later recall. A dictaphone was also used to record pavement conditions.

The spot tests requiring special equipment were the transverse slope measurements, the NASA grease smear test, and the photographs

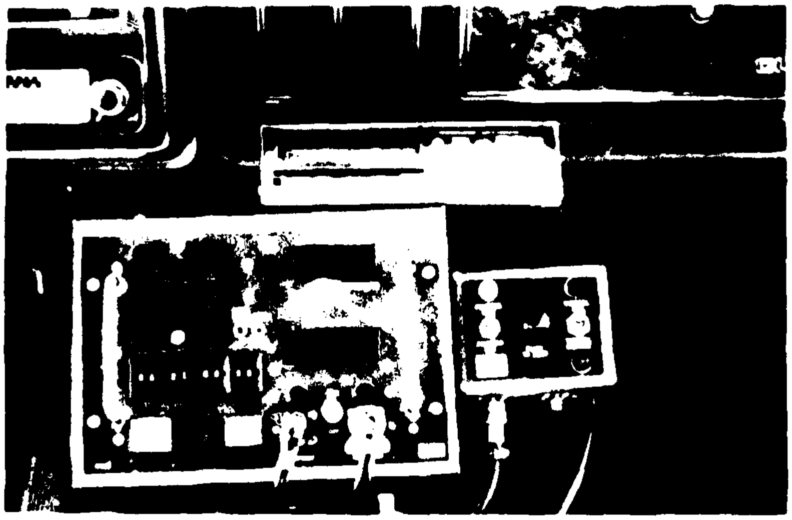


FIGURE 3. AUTOMATIC PRINTOUT UNIT AND TRANSWAVE

of the pavement surface. Transverse slope measurements were taken with the Fawley Slope Bar. The slope bar was a 4-foot level with a cam mounted on one end to vary the vertical distance from that end of the level to the runway. The cam was calibrated to read percent transverse slope directly. This is shown in Figure 4.

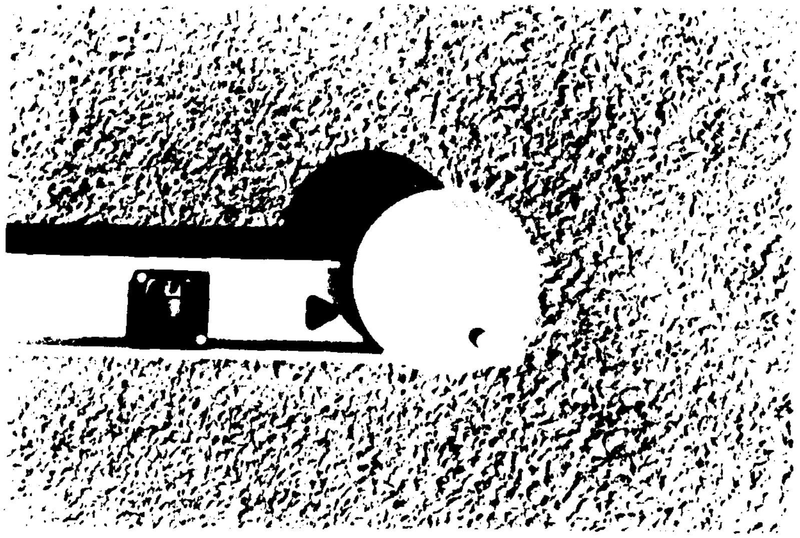


FIGURE 4. FAWLEY SLOPE BAR

Apparatus for the NASA Grease Smear test is shown in Figure 5. A selected volume of grease was smeared with the squeegee onto a 4-inch wide section of pavement delineated with masking tape. The volume divided by the area of the grease smear equals the average texture depth in inches.

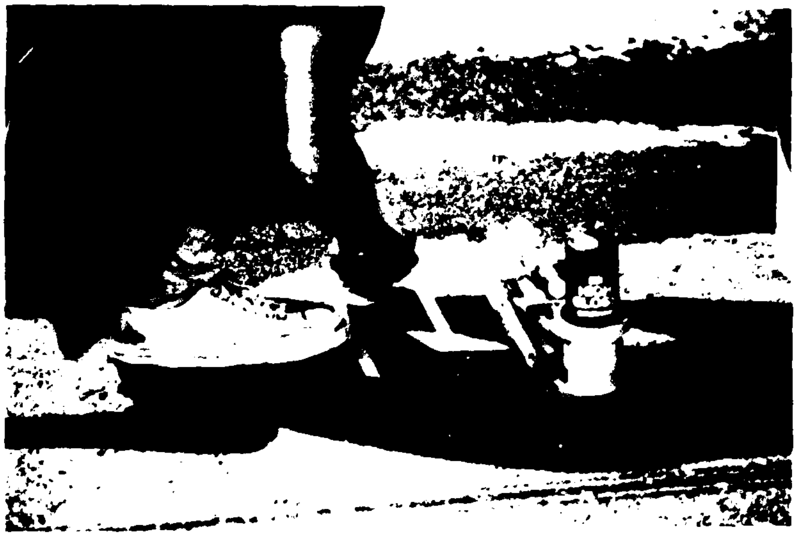


FIGURE 5. NASA GREASE SMEAR TEST

Photographs of the pavement surface were taken with two 35 mm cameras. They were mounted on a metal frame at an angle so that the photographs could be viewed with a stereoscope. Electronic flashes were used as a light source. Figure 6 shows the stereo camera fixture.

2.2.4 Data Entry Equipment

A portable terminal, which could access the computer through any common telephone, was used by the survey team to transmit and receive data and messages. Figure 7 shows the portable terminal in use by a survey team member. Two-wheel travel trailers were used as field offices and security storage space. A trailer is shown in Figure 8.

2.3 FIELD PROCEDURES

2.3.1 Introduction

The data gathering procedures were divided into two categories, friction measurements and airport inventory. Apart from

FIGURE 6. STEREO CAMERA FIXTURE

FIGURE 7. PORTABLE COMPUTER TERMINAL

FIGURE 6. TRAVEL TRAILER

Mu-Meter measurements, the category of friction measurements also includes related pavement observations and tests performed on the runway during a pavement condition survey. The airport inventory, mainly engineering and runway usage data, was obtained from reports and files at the airport office and by interviews with the airport manager or staff. Data parameters associated with the friction measurements and airport inventory are listed in Tables [illegible] and [illegible].

TABLE [illegible]. FRICTION MEASUREMENT DATA PARAMETER

Dry Mu Values - 500-foot averages
Wet Mu Values - 500-foot averages
Pavement, Air, and Water Temperature
Date, Time
Rating and Location For:
- Asphalt or Concrete
- Type of Finish
- Grooving Type
- Grooving Condition
- Rubber Accumulation
- Structural Distress
- Joint or Crack Condition
- Joint Type
- Joint Condition
- Contaminant Type
- Contaminant Coverage
- Depression, Rut, Depth
- Location and Offset from Centerline
- Transverse Slope

TABLE 2. (cont.)

- Texture measurements
- Groove dimensions (spacing, width, depth)
- Rubber accumulation
- Mu-Values - dry and wet
- Stereo photographs

TABLE 3. AIRPORT INVENTORY DATA PARAMETERS

Airport name
FAA Region
Airport Designator
Key personnel - names, titles, phone numbers
Airport mailing address
Master Plan date
Airport Layout Plan date
Aerial photographs date
Frost depth typical for area
Runway identification
Runway utilization
Landings by aircraft type
For each Runway:

- Length
- Width
- Elevation
- Effective gradient
- Design transverse slope
- Date of most recent painting
- Marking type
- Paint type and condition along centerline
- Grooving date
- Original construction - date, material, finish, length and location
- Subsequent additions and overlays - date, material, finish, length and location

Seal coating date
Design aircraft, weight and landing gear
Soil classification
Drainage condition
Rubber removal - date, method
Blast pads or displaced thresholds location and length
Previous friction measurements - date, results, source
Pavement tests, soil tests, dates
Known pavement deficiencies:

- Rutting
- Shoving due to traffic
- Faulting of slabs
- Excessive cracking
- Frost bumps during winter
- Longitudinal grade change
- Transverse grade change
- Poor drainage

TABLE 3. (cont.)

Loss of crown
Groove closing
Surface wear
Rubber accumulation
Other

Accident History:
Date
Runway
Equipment involved

The primary purpose of the data gathering process was the collection of pavement surface friction measurements. All other procedures were utilized to provide data for correlation with the friction measurements. The field procedures fell into the following general tasks, listed in chronological order:

1. Airport Contact Meeting

2. Airport Inventory

3. Mu-Meter Friction Tests

4. Pavement Condition Survey

5. Data Evaluation

The tasks are explained in greater detail in the following section.

2.3.2 Airport Contact Meeting

Before initial testing at an airport, the contractor corresponded with airport management to introduce the program and coordinate scheduling. The survey team held a contact meeting with airport staff before each survey to set up a testing schedule and collect airport inventory data.

2.3.3 Airport Inventory

The airport inventory consisted of engineering data, construction history and operations data for each runway tested. Engineering data included design aircraft, design transverse slope, effective gradient, soil classification, etc. During each survey, changes since the previous survey, such as a runway extension or surface treatment, were added to the airport inventory.

2.3.4 Mu-Meter Friction Tests

Prior to measurements at each airport, survey teams performed a functional check on the Mu-Meter in accordance with the manufacturer's instructions. At the starting end of the runway, the Mu-Meter measuring wheels were put in test position and the tow vehicle was aligned ten feet to the right of the runway centerline. The dry friction survey was started after obtaining clearance from ground control. The tow vehicle was brought up to

40 mph within the first 500 feet and maintained at this speed by the automatic speed control until the final 200 feet. The survey team observed runway surface changes and monitored the APC digital display to make certain that the Mu-Meter was functioning. A [illegible] survey was also performed on the opposite side of the runway.

In the same manner, wet friction runs were conducted on the runway. After the tow vehicle was positioned at the end of the runway, the survey team lowered the water distribution brushes and recorded the amount of water in the water tank. The length of time the pump was activated and the amount of water used were determined and the flow rate was computed.

2.3.5 Pavement Condition Survey

The Pavement Condition Survey was the assessment of pavement surface conditions throughout the runway based on visual observations, and measurement of surface conditions at four spot test locations. A glossary of terms used for classification of pavements and the Pavement Condition Survey are found in Appendix B. The main area of concern on the runway was in the Mu-Meter testing tracks, from 8-12 feet on either side of the centerline.

During the first test run of the pavement condition survey, a record was made of the following surface conditions for the entire runway length: pavement type, grooving type and condition, contaminant type and coverage, paint type and coverage, cracking, joints, and rut or depression depth. Additional pavement data were collected at four spot test locations. The spot tests included photographs, transverse slope measurements, groove spacing measurements, and the NASA grease smear test.

The final test run of the pavement condition survey was to measure rubber accumulation. Rubber accumulation was rated based on the percent of the texture that was obliterated by the rubber. The entire testing time for four Mu-Meter runs and two pavement condition survey runs was approximately 1-2 hours per runway.

2.3.6 Data Evaluation

The survey team evaluated and coded the data for computer input. All the Mu-Meter strip charts were evaluated: The continuous trace was divided into 500-foot segments of runway surface and an average Mu-Meter surface friction value (Mu value) was determined for each segment. The Mu values were also read for each spot test location on the runway.

To provide guidance to the survey teams, limits of acceptability were established based upon the experience gained in the first half of the program. Reasonable agreement between the average surface friction for an entire runway for two passes, separated by at least 30 days, was considered to be ± 3 Mu values. When comparing three passes, the Mu value tolerance between the highest and lowest runway Mu averages was ± 4, and for four passes, ± [illegible]. In addition, each individual 500-foot segment Mu value was to be within the tolerance of ± 6, ± [illegible] and ± 9 for two, three and four

passes respectively. Survey team members also checked that the strip chart profile was similar for all passes. If a runway fell outside these guidelines it was further investigated, and if necessary retested. Pavement changes, measurement variability and climatic conditions affecting the limits of acceptability are further discussed in Section 2.6.5.2.

If a runway fell within the limits of acceptability, the data were recorded on computer entry forms. It was then entered into the computer and checked with a computer program.

2.4 QUALITY CONTROL

The quality control aspect of the National Runway Friction Measurement Program was designed to insure consistency and accuracy of data. Quality control was divided into two major tasks. The first was to insure consistency in survey team procedures and quantitative judgements. The second task was to insure accuracy in transferring raw data to computer files, forms, and reports.

To insure consistency in survey team procedures and quantitative judgements, a Quality Control Manual was developed. The quality control team included senior members of the contracting firm who were familiar with all phases of field operations.

Quality control personnel periodically joined survey teams in the field to evaluate team performance. Their function was to observe and evaluate the field team rather than participate in the work. After each visit, they filled out a Quality Control Checklist and wrote a short summary of the evaluation, giving recommendations for improvements where needed. Team/office meetings also helped to insure consistency in survey procedures. Team members compared pavement condition ratings of photographs and discussed procedures with each other and office personnel.

The second quality control task was to insure accuracy in transferring raw data to computer files, forms, and reports. When a survey team finished gathering data at an airport, the data were entered into a computer file. A visual check was made of the raw data, the computer entry coding forms, and the airport computer file. The last step of data entry for the survey team was to computer check the data file for entry errors and data acceptability.

When the survey team completed each airport data file, the home office received and evaluated the data. A computer program used the airport data file to generate an airport survey report. The computer-generated survey report was checked against the data entry forms, and Mu values were checked against the Mu-Meter strip chart.

When the computer file was correct, a second program was used to compare the first and second survey airport data. Survey teams used these forms as background information to be verified by the airport staff. Throughout this process any errors which were found were corrected. Finally, the home office transferred the data into the data base.

2.5 COMPUTER OPERATIONS

A large computer capability was required for fast and accurate storing, sorting, processing and retrieving of the more than 650,000 individual data items which were collected during the program. The computers served several functions: high speed communication, data access, error checking, and statistical analyses.

The Direct Access Computing time-sharing network services of McDonnell Douglas Automation Company (McAuto) were used for data access and communications. These services are based on a [illegible] 75 computer and have nationwide access. The University of Minnesota CDC [illegible] computer was used for the statistical [illegible] of the data.

[illegible]

[illegible] Data Entry

[illegible] the completion of each airport survey the team coded and entered the collected data using the portable computer terminal. Data entry forms aided the survey team in organization and format of the data into a logical unit, the airport computer file. [illegible] airport computer file was named with the corresponding airport designator. The results of the airport surveys were thus immediately available for examination and processing by the Contractor and FAA Technical Officer.

2.5.3 Airport Survey Reports

A standard Airport Survey Report presented the data of the friction measurements, the pavement condition survey and the spot tests for each runway with an evaluation and discussion of the data. A computer program used the airport computer file to generate the data in table format and evaluated the data according to standards in the FAA Advisory Circular 150/5320-12. A sample Airport Survey Report is shown in Appendix C.

2.5.4 Statistical Analysis

To organize the data, a data base was developed using System 2000 on a CDC Cyber computer. The data base structure was based on the logical groupings of data into Region, Airport, Runway, and Test with data for each of the units relatable to each preceeding unit.

Statistical analyses of the parameters involved in the characterization of runway friction were performed using SPSS. SPSS is a nationally vended computerized statistical package selected for its capability of analyzing extensive data sets with a large number of variables. All analyses were performed using the most current algorithms for maximum processing efficiency.

2.6 ENGINEERING EVALUATION

2.6.1 Data and Methods of Analysis

From November 1978 through August 1980 surface friction measurements and a variety of other data were obtained at 268 airports on 491 runways. Each runway was tested on three different occasions (in a few instances, two or four occasions), with successive test dates separated by at least 60 days. See Appendix A - National Runway Friction Measurement Program Survey Dates. This program produced a huge volume of data, including replicate friction measurements of the entire length of every scheduled turbo-jet runway in the 48 contiguous United States. From a statistical standpoint, these data represent not a sampling, but en masse measurement of the whole runway population of interest. To have such extensive data for predictive analysis is very rare.

After each testing at an airport, a report of the results was produced and submitted to the FAA, who in turn forwarded a copy to the airport management. See Appendix C - Sample Airport Survey Report. These reports provided rapid feedback to the airport management. Going beyond this short-term use of the data obtained, the following engineering evaluation considers the data as a whole and interprets the data through statistical and analytical means.

The greater portion of the data consists of Mu values and other pavement measurements averaged over 500-foot long runway segments. Including all runways and test dates, the data base contains over 42,000 such segments. Apart from surface friction data, each segment is characterized by pavement material and finish, presence or absence of grooving, groove condition, rubber accumulation and several other conditions (see Table 2). Statistical analysis of segment data was confined to some 29,000 uniform segments, defined as those segments (1) having at least 490 feet of the same pavement material, finish and presence or absence of grooving, (2) having no paint markings, ruts, depressions or contaminants other than rubber, and (3) located at least 200 feet from the runway end, thereby excluding acceleration and deceleration zones. Characteristics of these 29,000 uniform segments are found in Appendix D. Other data analyzed included some 5,630 spot measurements of texture depth (NASA grease smear test) and data obtained from airport management on runway usage, construction and rubber removal.

The data analysis was performed with a standard, computerized statistical package (SPSS). The primary methods employed were multiple regression and correlation. The analysis was guided by continual inspection of graphed data and of summary statistics, as well as by the considerable first-hand field experience derived from the program. Residual analysis was employed in reviewing the outcome of regression runs and led to identification of unique circumstances, thereby allowing verification of the data prior to drawing general conclusions. A more detailed description of the data used in each analysis is included in Appendix E.

2.6.2 Evaluation of Pavement Types

2.6.2.1 Mean Surface Friction Values - Seventeen pavement surfaces are distinguished on the basis of material and finish, as [illegible] in Appendix [illegible] - Photographs of Pavement Types. [illegible] the presence or absence of saw-cut grooving, [illegible] pavement types have sufficient data for analysis. An additional [illegible] types represented by only one or two runways are not discussed explicitly. It should be noted that within each classification occasionally an individual runway pavement exhibits atypical characteristics, resulting from peculiarities of aggregate source or other factors. Although the scope of this program did not permit such an investigation, it may be desirable to study the relationship of geological origin of aggregate to pavement surface friction. The stereo photographs obtained as part of this program appear to offer considerable promise as a tool in investigating the pavement properties which affect friction characteristics.

Mean wet surface friction values for each of the 28 pavement types are presented in Table 4 - Mean Wet Mu Values for Pavement Types. Note that the values are reported on a scale of zero to [illegible] and that wet Mu values were measured with a controlled water depth of 1.0 mm or 0.04 inches.

For pavement areas having no rubber accumulation, the mean wet Mu values for pavement types range from 57.9 to 77.4. It is apparent from Table 4 that pavement grooving and rubber accumulation have major effects on pavement surface friction. These effects are discussed in Sections 2.6.3 and 2.6.[illegible], respectively.

The 28 pavement types are displayed in rank order by mean [illegible] friction value for areas with no rubber, in Figure 9 - Ranking of Pavement Types by Mean Wet Mu Value. It is emphasized that this ranking is based on surface friction only. The choice of runway pavement type depends upon a variety of important considerations, of which surface friction is only one.

It is of particular interest in Figure 9 that the sequence of ungrooved asphalt pavement types corresponding to increasing age ([illegible] new, microtexture, mixed texture, macrotexture, worn) also corresponds to increasing surface friction.

2.6.2.2 [illegible] - Table 5 - Mean Texture Depth for Various Pavement Types [illegible] data based on NASA grease smear tests in pavement areas with traffic but no rubber accumulation. The test measures a combination of macrotexture and microtexture with the mean values ranging from [illegible].5 to 48.5 thousandths of an inch, and it is obvious that pavements with texture exceeding 50 thousandths of an inch are relatively rare. It is notable that grooved pavement types generally have textures (measured between, not including, the grooves) somewhat shallower than the corresponding ungrooved types. Float grooved runway surfaces have a low texture which produced a correspondingly low surface friction.

TABLE 4. MEAN WET MU VALUES FOR PAVEMENT TYPES

ASPHALT PAVEMENTS

Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
New	61.9	46.8
Microtexture	65.8	54.5
Mixed Texture	68.4	50.9
Macrotexture	74.1	55.7
Worn	74.6	55.1
Porous Friction Course	77.4	67.4
Chip Seal	75.1	--
Rubberized Chip Seal	73.0	--
Slurry Seal	70.2	--

ASPHALT WITH SAW-CUT GROOVES

Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
New	73.2	63.7
Microtexture	75.0	66.5
Mixed Texture	73.7	64.8
Macrotexture	73.5	67.4
Worn	71.6	--

CONCRETE PAVEMENTS

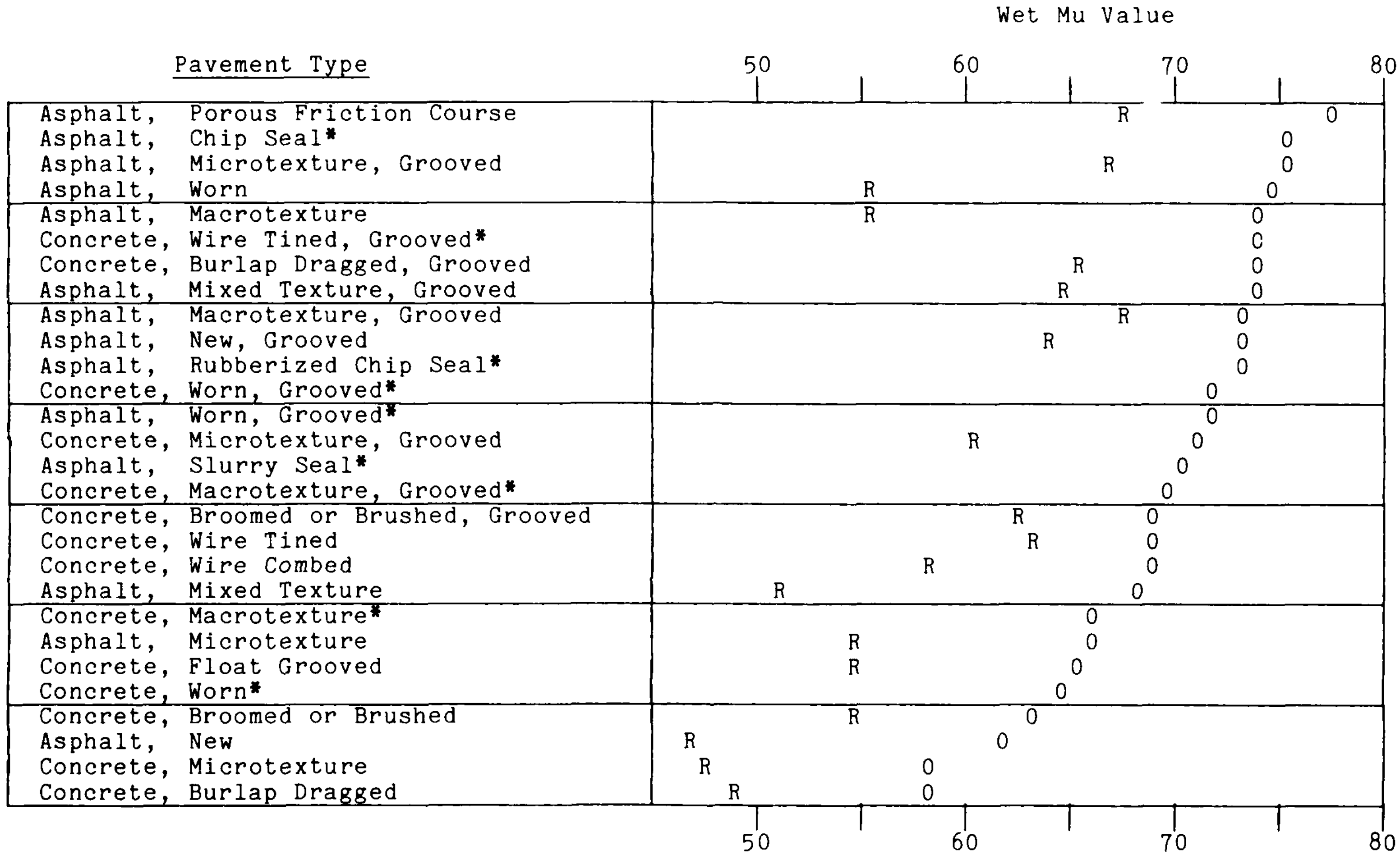
Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
Microtexture	57.9	47.6
Macrotexture	66.2	--
Worn	64.2	--
Burlap Dragged	57.9	49.1
Broomed or Brushed	63.3	54.7
Wire Combed	68.6	58.3
Wire Tined	69.1	63.0
Float Grooved	65.6	54.7

CONCRETE WITH SAW-CUT GROOVES

Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
Microtexture	71.1	60.0
Macrotexture	69.7	--
Worn	72.0	--
Burlap Dragged	73.7	65.0
Broomed or Brushed	69.2	62.8
Wire Tined	73.8	--

*Mean Mu value adjusted for 30 percent filling of texture by accumulated rubber, for pavement types with sufficient data for regression analysis. (See Section 2.6.4.1).

NOTE: Data include all uniform segments. See Appendix F.



0 - Mean Value with No Rubber
R - Mean Value in Rubber Areas (30% rubber accumulation)
* - Insufficient Data to Analyze in Rubber Area

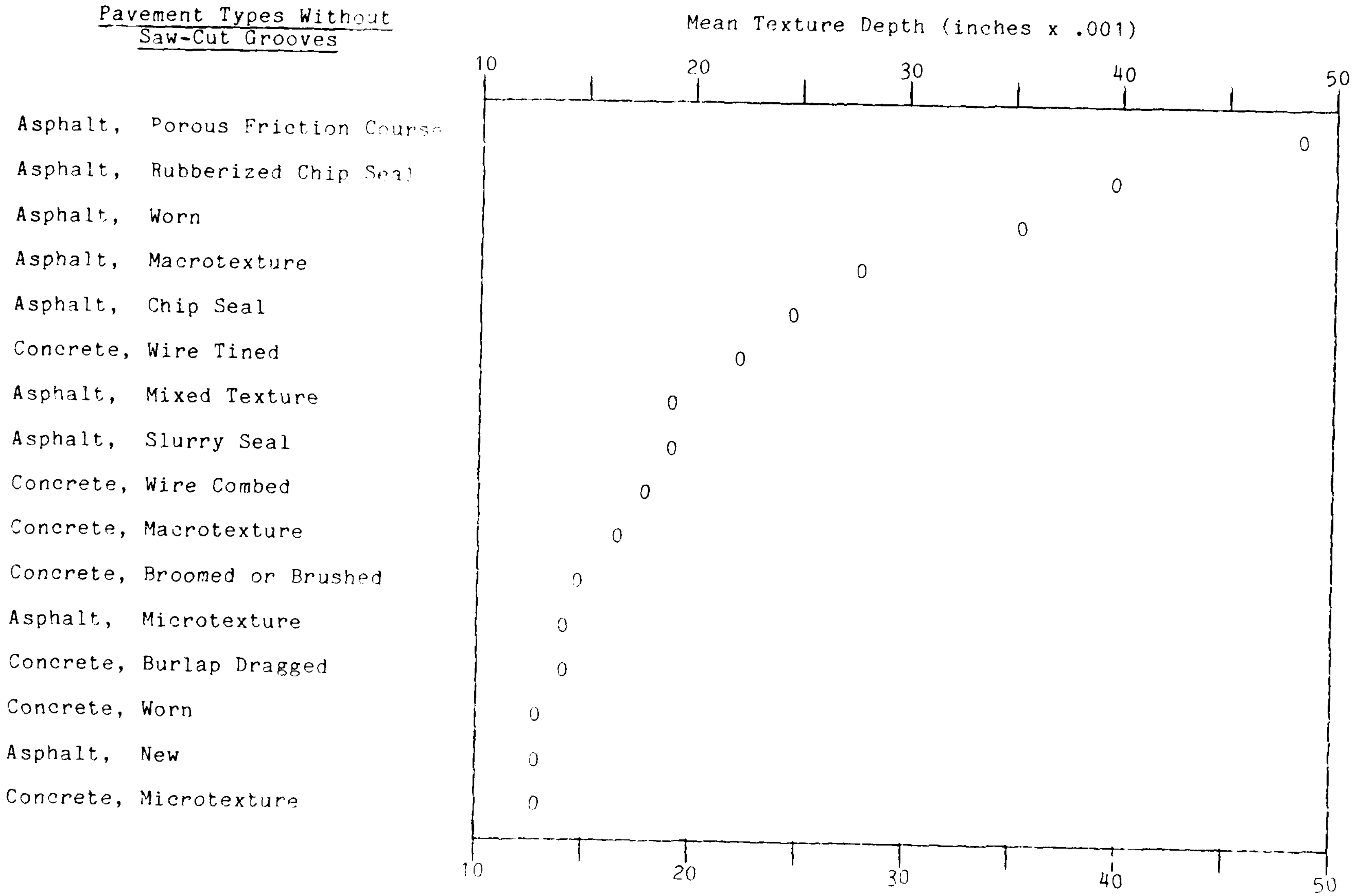
NOTE: Data include all uniform segments. See Appendix E.

FIGURE 9. RANKING OF PAVEMENT TYPES BY MEAN WET MU VALUE

TABLE 5. MEAN TEXTURE DEPTH FOR VARIOUS PAVEMENT TYPES

Pavement Type	Mean Texture Depth inches x .001 Ungrooved	Saw-Cut Grooved
Asphalt, Porous Friction Course	48.5	
Asphalt, Rubberized Chip Seal	39.9	
Asphalt, Worn	35.0	24.7
Asphalt, Macrotexture	27.7	23.3
Asphalt, Chip Seal	24.7	
Concrete, Wire Tined	22.2	20.9
Asphalt, Mixed Texture	19.3	15.9
Asphalt, Slurry Seal	19.0	
Concrete, Wire Combed	18.0	
Concrete, Macrotexture	16.5	12.0
Concrete, Broomed or Brushed	14.5	10.5
Asphalt, Microtexture	14.2	12.7
Concrete, Burlap Dragged	13.9	11.9
Concrete, Worn	12.8	12.8
Asphalt, New	12.5	15.3
Concrete, Float Grooved	12.5	
Concrete, Microtexture	12.4	11.0

NOTE: Data include all center spots (traffic area) with no rubber accumulation. See Appendix E.



NOTE: Data include all center spots with no grooving and no rubber accumulation. See Appendix E.

FIGURE 10. RANKING OF PAVEMENT TYPES BY MEAN TEXTURE DEPTH

The 16 ungrooved pavement types (excluding all saw-cut grooving and also float grooved concrete) are shown ranked by texture in Figure 10 - Ranking of Pavement Types by Mean Texture Depth. The similarity in pavement type ranking shown by Figures 9 and 10 confirms that surface friction and texture depth are closely related. This relationship was further investigated.

Figure 11 - Relationships of Wet Mu Value with Texture Depth for Ungrooved Pavements, exhibits regression lines for surface friction as a function of texture depth. "Spot" friction values for each texture depth location were read directly from the Mu-Meter strip chart for this analysis. Pavement areas with traffic but no rubber accumulation are considered. The two curves in the figure for asphalt and concrete pavements reflect that texture is indeed a fundamental determinant of surface friction.

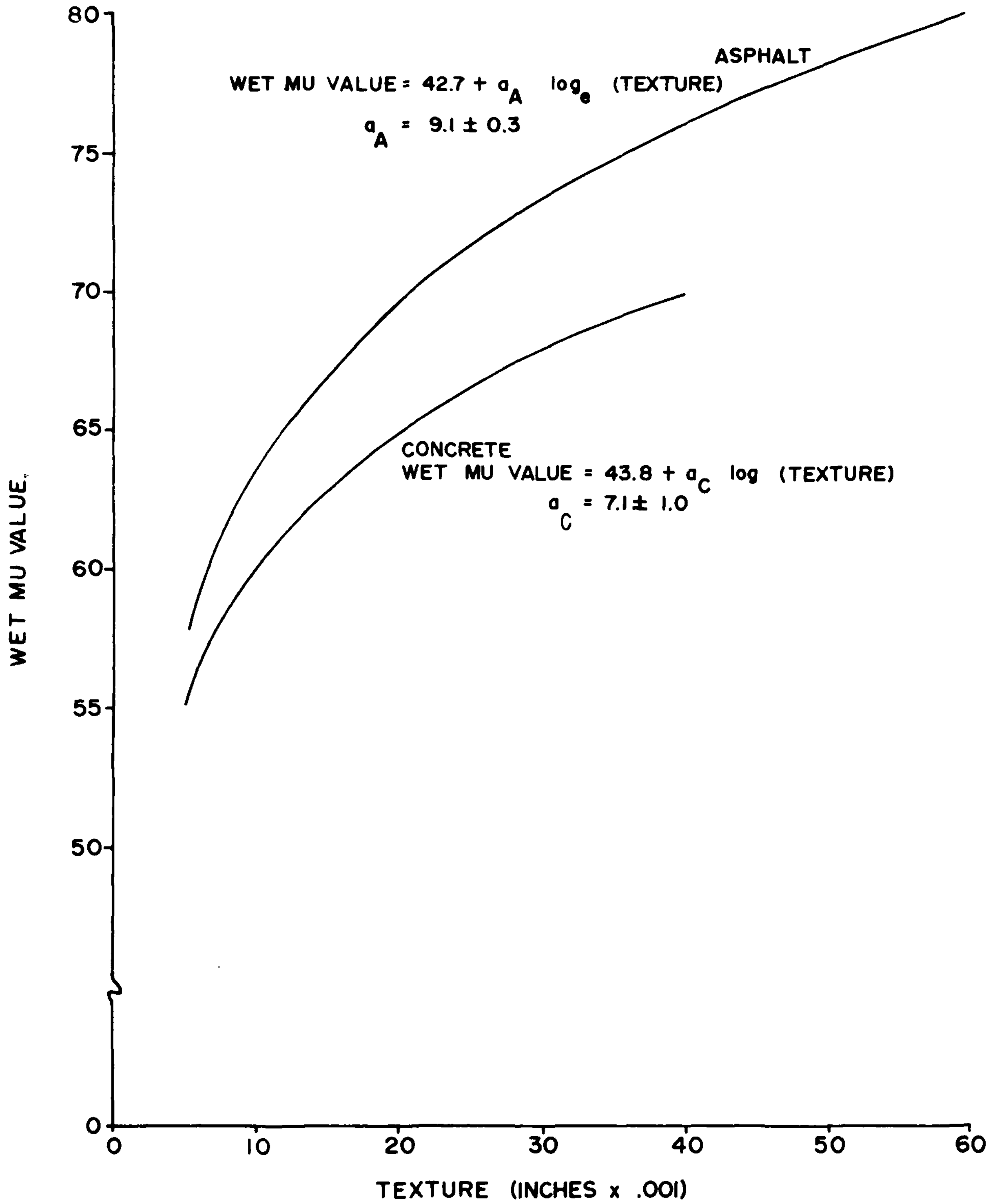
2.6.2.3 *Texture Wear and Weathering* - Visual and photographic observations formed the basis for classifying pavement types during the course of the program, and analysis afterwards confirmed that pavement age (i.e., time since construction or resurfacing, whichever was later) corresponds in the expected manner with pavement type. Moreover, the indication is that texture depth increases with pavement age. This can be explained by the increasing exposure of rough aggregate surfaces as pavement matrix weathers or is worn away.

The relationship of texture to pavement age appears to be a complex function in which the rate of change in texture increases with the pavement age. For asphalt ungrooved pavement surfaces in traffic areas with no rubber, the annual rate of change varies from less than 0.4 thousandths during the first year to more than four thousandths after 10 years. Data on concrete pavement age were insufficient for similar analysis, but it appears that texture of concrete pavements also increases with age, though at a slower rate than for asphalt.

Comparison of the above results with a similar analysis for nontraffic areas reveals that weathering, rather than pavement wear, is the primary cause of texture increase, at least for asphalt pavements. This conclusion rests on the fact that traffic and nontraffic pavement areas show essentially the same rate of texture increase. (Resulting nontraffic rate is slightly lower, as might be expected, but not statistically different.)

The above analysis excluded porous friction course and pavements with special seals. It was observed that some pavements which were originally finished with extremely coarse texture have weathered to a condition of lesser texture.

2.6.2.4 Summary of Pavement Evaluation - The mean surface friction values given in Table 4 for nonrubber areas, imply the ranking of 28 pavement types displayed in Figure 9. This ranking is based on surface friction alone; choice of a runway pavement type depends upon several important considerations. Pavement grooving and rubber accumulation have pronounced effects on surface friction as will be further discussed below. Texture



NOTE: DATA INCLUDE ALL CENTER SPOTS WITH NO RUBBER ACCUMULATION
SEE APPENDIX E

FIGURE 11. RELATIONSHIPS OF WET MU VALUE WITH TEXTURE DEPTH FOR UNGROOVED PAVEMENTS

depth is a fundamental determinant of surface friction. Interestingly, weathering of typical pavements causes texture depth to increase; the rate of change in texture increases with pavement age.

2.6.3 Evaluation of Pavement Grooving

2.6.3.1 General Effects of Grooving - The primary purpose of grooving is to provide improved drainage at the tire-pavement interface to reduce the potential for hydroplaning. In addition, it improves the friction characteristics of the pavement surface.

NASA tests on grooved pavements indicated that grooves spaced on the order of one inch could achieve this objective. FAA recommends the 1¼-inch groove spacing as the optimum practical standard consistent with these findings.

Since pavement texture is fundamentally related to surface friction, it is not surprising that techniques aimed at increasing the macro-scale texture of pavement are successful at increasing surface friction. Such techniques include plastic texturing of concrete pavements, surface treatment of asphalt pavements and saw-cut grooving of both asphalt and concrete pavements. This analysis focuses on saw-cut grooving, which includes 11 pavement types.

The fact that grooving enhances surface friction of runway pavements is evident from inspection of Table 4 - Mean Wet Mu Values for Pavement Types, discussed in Section 2.6.2.1. A different view is afforded by Figure 12 - Example of Effect of Saw-Cut Grooving on Runway Surface Friction, which shows data for a specific runway. As the figure shows, grooving enhances surface friction throughout the runway length.

Figure 13 - Comparison of Wet Mu Values for Saw-Cut Grooved with Ungrooved Pavement, exhibits previously presented data in a manner which emphasizes the effects of grooving on surface friction. Pavement types are ranked in Part A of the figure according to mean wet Mu value in areas without rubber accumulation for the grooved types. Mean values for corresponding ungrooved types are shown for comparison. Part B of Figure 13 shows a similar comparison for areas with 30 percent rubber accumulation, as determined by regression analysis described in Section 2.6.4.1. (Note that 30 percent rubber accumulation means a level of accumulation which obliterates 30 percent of the pavement texture.) Figure 13 illustrates that saw-cut grooving generally enhances surface friction in uncontaminated areas, while in areas of rubber accumulation the increase in friction due to grooving is more pronounced.

2.6.3.2 Effect of Groove Spacing - The effect on surface friction of groove spacing was investigated by multiple regression. Measured groove spacings were sorted into classes corresponding to class-means of 1.25, 1.5, 1.75, 2.0, 2.25, 2.5, 2.75 and 3.0 inches. It was found for various grooved pavement types that a one-inch difference in groove spacing corresponds typically to a

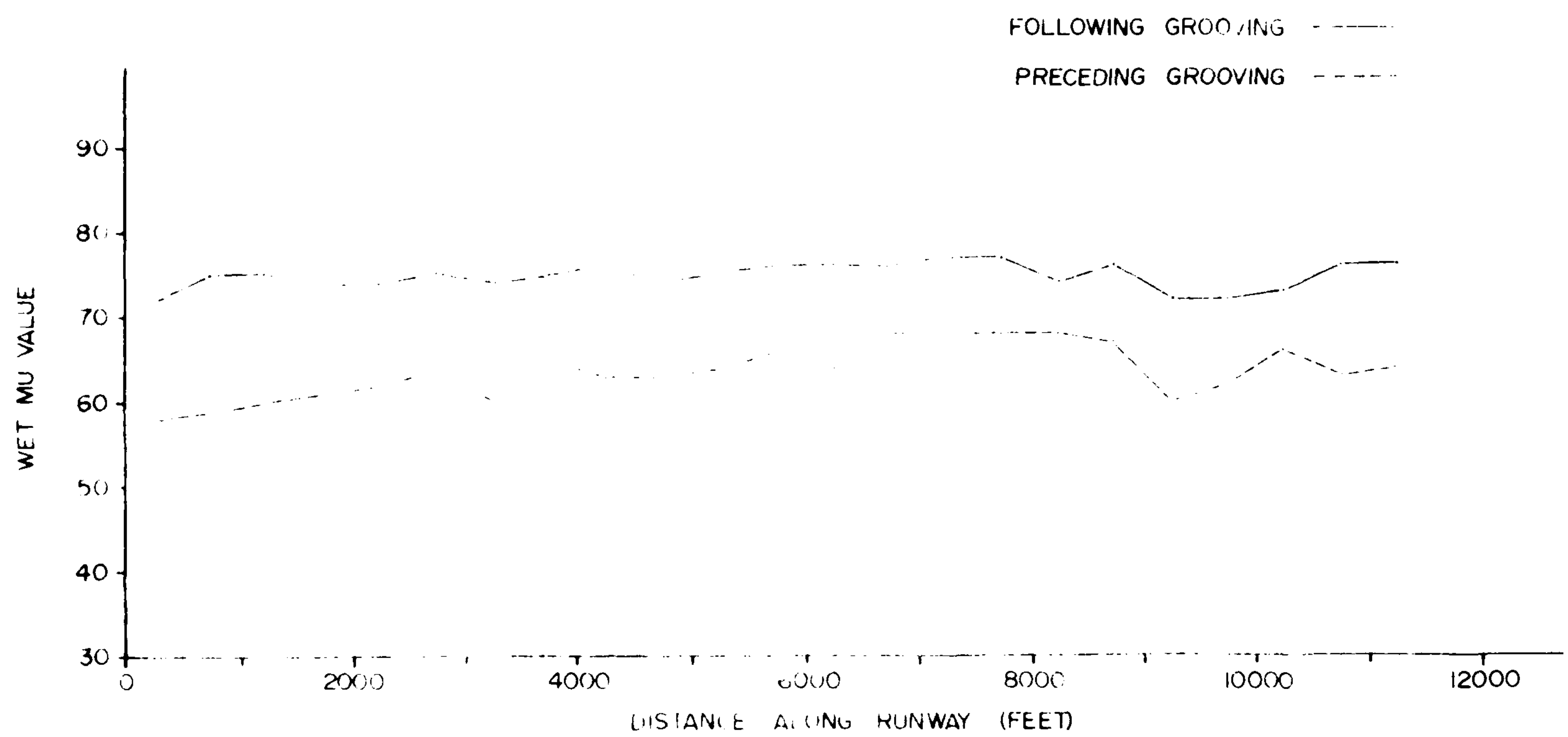
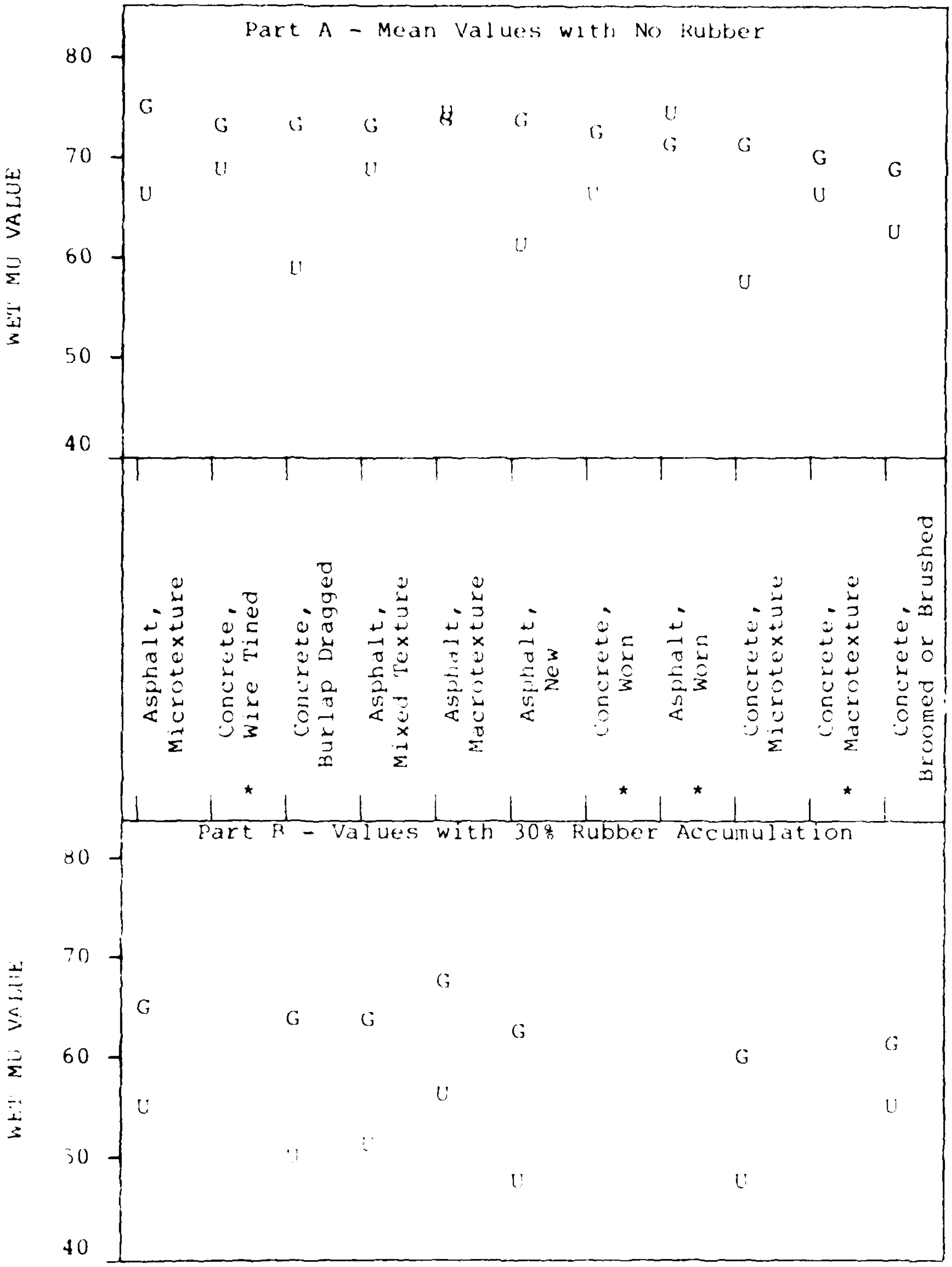


FIGURE 12 EXAMPLE OF EFFECT OF SAW CUT GROOVING ON RUNWAY SURFACE FRICTION



G - Saw-Cut Grooved
U - Ungrooved
* - Insufficient Data for Analysis

NOTE: Data include all uniform segments. See Appendix E.

FIGURE 13. COMPARISON OF WET MU VALUES OF SAW-CUT GROOVED PAVEMENT WITH UNGROOVED PAVEMENT

five-wet Mu value difference in friction (with typical standard error one wet Mu value per inch). The regression results indicate that, within the range of spacings encountered, surface friction increases as groove spacing decreases. That is, the enhancement of friction is greater for narrower spacing. At the other extreme, very little friction enhancement results with the widest groove spacings.

It is therefore desirable from the standpoint of friction to use smaller saw-cut groove spacings. The standard groove spacing of 1¼ inches center to center is indicated as best in the range encountered in the program.

2.6.3.3 Effect of Groove Deterioration - Groove deterioration was also considered in the multiple regression analysis. The deterioration of grooving is represented in a scale from zero (good condition, uniform depth across runway) to nine (essentially ineffective). For example, a groove deterioration of three means from 30 to 39 percent ineffective, due to being filled or missing or poorly built.

Based on the above rating scale, the regression results for saw-cut grooved pavements are typically one wet Mu value decrease in friction per unit increase in groove deterioration. The standard error is approximately 0.5 wet Mu value per unit of groove rating.

2.6.3.4 Groove Deterioration and Climate - There are known cases of grooved asphalt pavements on which the grooves have closed up, apparently as a result of traffic during high summertime temperatures. A statistical relationship for asphalt pavement was therefore sought between groove deterioration, as defined in the previous section, and climate, represented by frost depth and by mean daily maximum temperature for the hottest month. Multiple regression analysis yielded no relationship for temperature and only a weak relationship for frost depth.

2.6.3.5 Summary of Grooving Evaluation - Saw-cut grooving of runway pavements has a definite, positive effect on surface friction, as can be seen in Figure 13. Grooving enhances friction in areas of rubber accumulation to a greater degree than in areas with no rubber. The effect of groove spacing is that friction enhancement is greater for narrower spacing. As grooves deteriorate in condition, the enhancement of friction also decreases slightly.

2.6.4 <u>Evaluation of Rubber Removal Effectiveness</u>

2.6.4.1 Effects of Rubber Accumulation on Surface Friction - Rubber accumulation on runway pavement profoundly affects surface friction, as is evident from Figure 9 in Section 2.6.2.1. For a particular runway, a graph of wet Mu value versus distance generally has lowest friction values in areas of highest rubber accumulation. Figure 14 - Example of Effects of Rubber Accumulation and Removal on Runway Surface Friction, illustrates this. Figure 14 also shows that rubber removal can result in increased surface friction, as will be further discussed below.

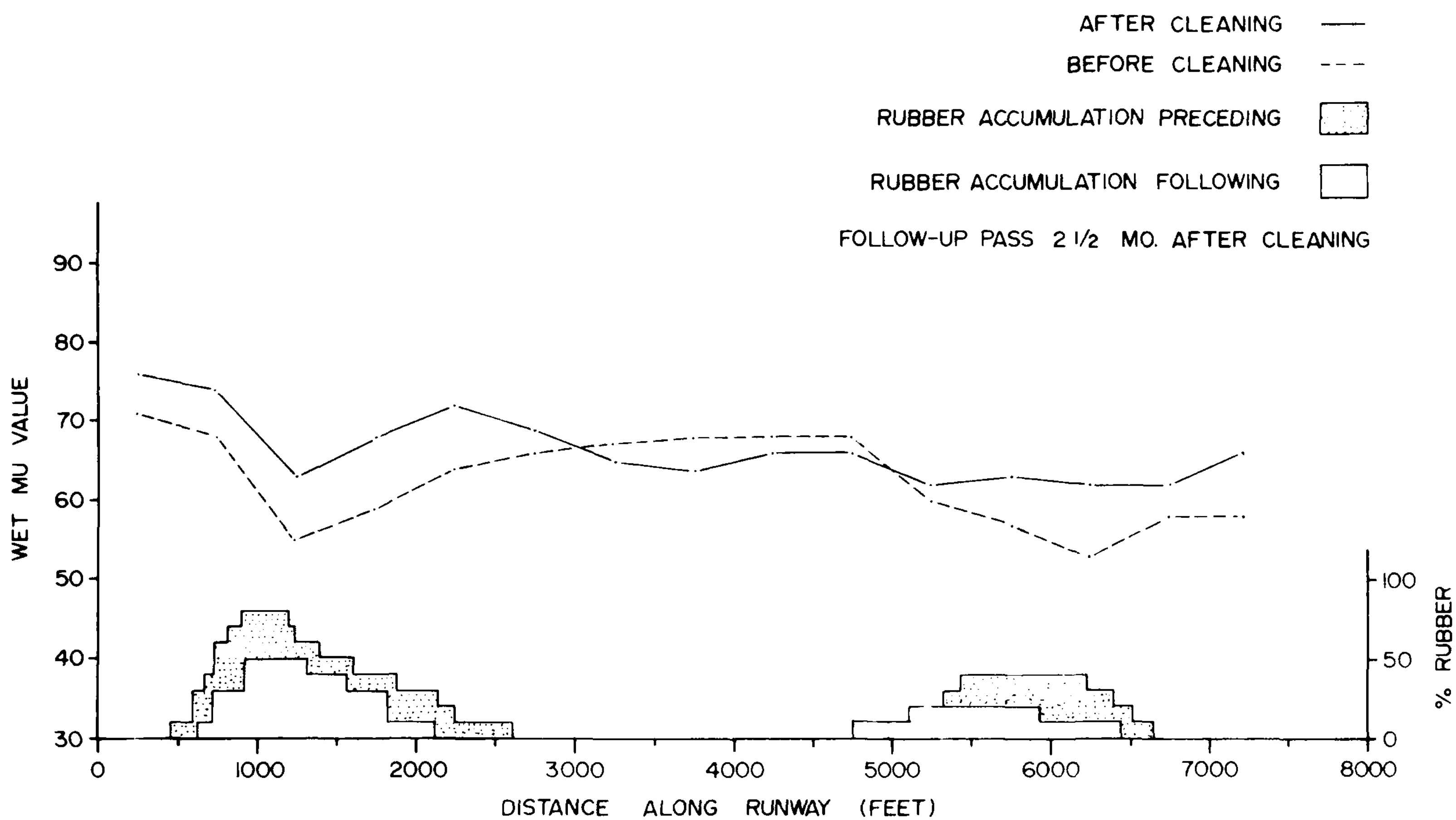


FIGURE 14. EXAMPLE OF EFFECTS OF RUBBER ACCUMULATION AND REMOVAL ON RUNWAY SURFACE FRICTION

Linear relationships between surface friction and degree of rubber accumulation were developed through multiple regression analysis of data for the 500-foot runway segments. The analysis excluded segments with no rubber accumulation, as these are the overwhelming majority and would tend to weight the results unduly. For individual pavement types with sufficient data for analysis, equations were obtained of the following form:

$$M = b - m \cdot R \qquad (1)$$

in which

M = wet Mu value segment average;

b = intercept constant, having units of Mu values;

m = slope constant, having units of Mu values per unit of rubber accumulation; and

R = rubber accumulation segment average measured in units from zero (no rubber) to nine (essentially complete obliteration of pavement texture by rubber).

The results are presented in Table 6 - Regression Constants Relating Surface Friction to Rubber Accumulation. The constants b and m reported in Table 6 are as appear in Equation 1. Note that for grooved pavement types the reported constants have been adjusted for the simultaneous influences of groove spacing and groove condition, and the intercept b reflects the mean values (for each such pavement type) of groove spacing and condition.

An important observation from Table 6 is that the slope m for saw-cut grooved pavements is generally on the order of one-half the corresponding slope for ungrooved pavements. (The only exception to this is new asphalt, which has a relatively small data set when restricted, as in this analysis, to 500-foot segments with significant rubber accumulation.) This means that the surface friction of saw-cut grooved pavements is less sensitive to rubber accumulation than is the surface friction of ungrooved pavements.

Consider for example microtexture concrete pavement. From Table 6 the regression slope m is 6.9 Mu value per unit of rubber accumulation for the ungrooved pavement type, and 3.5 Mu value per rubber unit for saw-cut grooved. Thus the decrease in wet Mu value for, say, a two-unit increase in rubber accumulaion is approximately 14 for ungrooved, and 7 for saw-cut grooved, microtexture concrete pavement.

The regression lines defined by the slopes and intercepts in Table 6 are shown graphically in Figure 15 - Relationship of Wet Mu Value with Rubber Accumulation for Asphalt Pavements and Figure 16 - Relationship of Wet Mu Value with Rubber Accumulation for Concrete Pavements. Note that the actual ranges of rubber values found in the data for each pavement type are indicated by the solid portions of the regression lines in Figures 15 and 16.

TABLE 6. REGRESSION CONSTANTS RELATING SURFACE FRICTION TO RUBBER ACCUMULATION

ASPHALT PAVEMENTS

Type	Intercept, b	Slope, m	Standard Error of m
New	55.2	2.8	± 1.2
Microtexture	63.8	3.1	± 0.2
Mixed Texture	65.0	4.7	± 0.2
Macrotexture	73.4	5.9	± 0.6
Worn	67.7	4.2	± 0.6
Porous Friction Course	78.8	3.8	± 0.3

ASPHALT WITH SAW-CUT GROOVES

Type	Intercept, b	Slope, m	Standard Error of m
New	77.2	4.5	± 0.9
Microtexture	72.2	1.9	± 0.2
Mixed Texture	70.5	1.9	± 0.1
Macrotexture	73.4	2.0	± 0.3

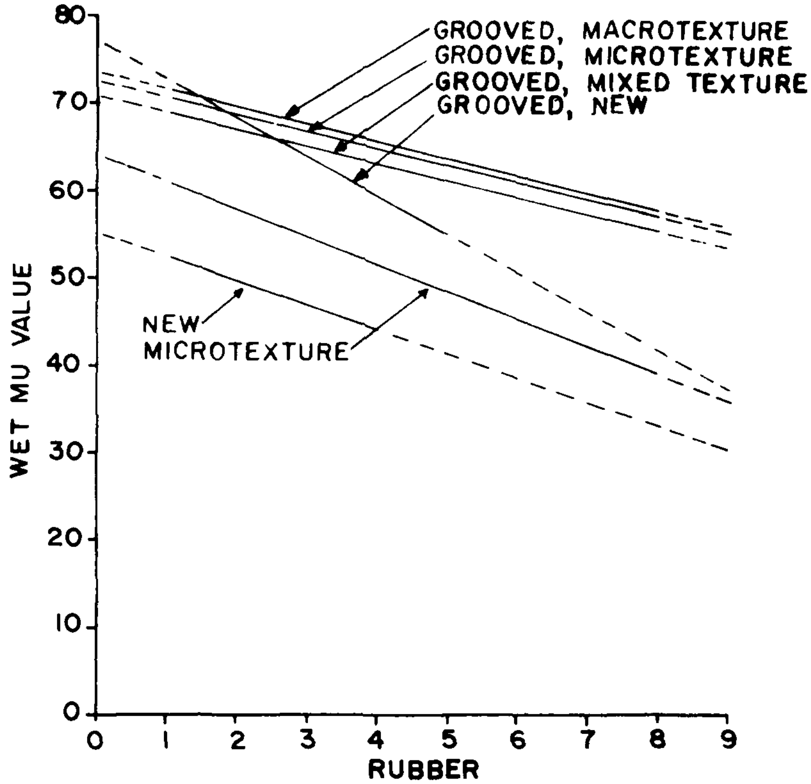
CONCRETE PAVEMENTS

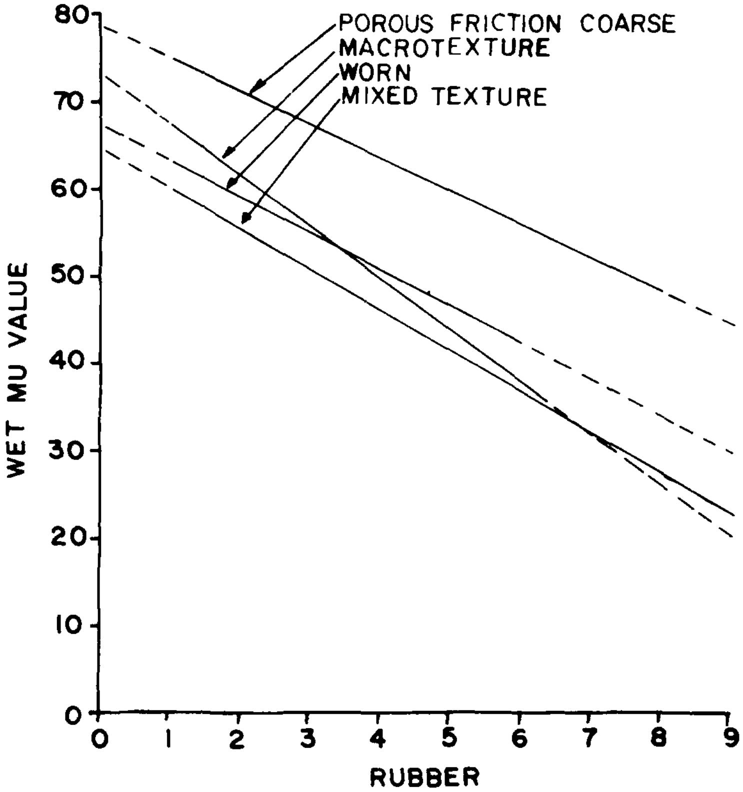
Type	Intercept, b	Slope, m	Standard Error of m
Microtexture	68.3	6.9	± 0.9
Burlap Dragged	61.1	4.0	± 0.3
Broomed or Brushed	66.7	4.0	± 0.4
Wire Combed	70.0	3.9	± 0.7
Wire Tined	68.4	1.8	± 0.5
Float Grooved	61.6	2.3	± 0.6

CONCRETE WITH SAW-CUT GROOVES

Type	Intercept, b	Slope, m	Standard Error of m
Microtexture	70.5	3.5	± 0.6
Burlap Dragged	73.7	2.9	± 0.2
Broomed or Brushed	67.6	1.6	± 0.4

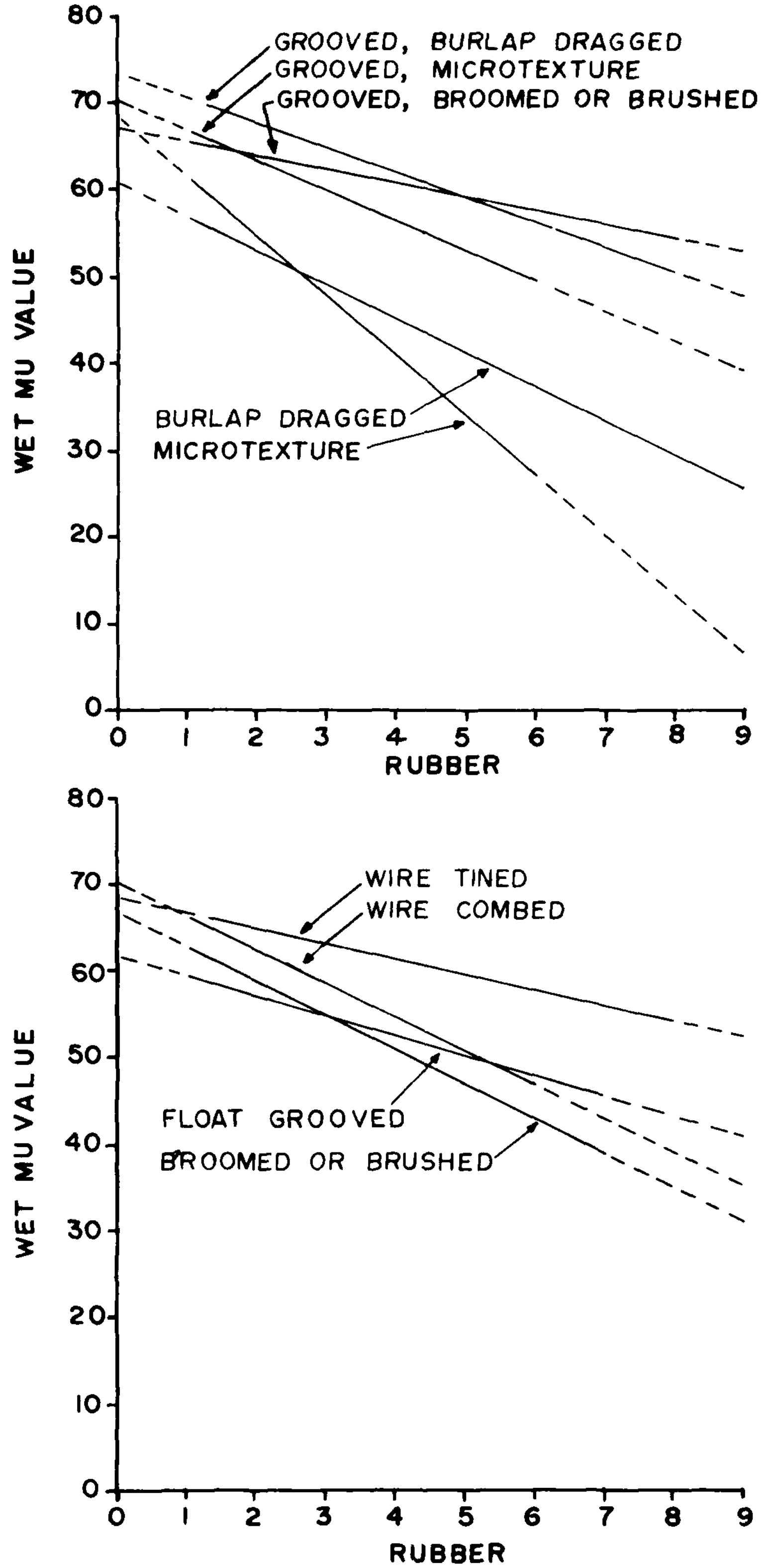
NOTE: Data include all uniform segments. See Equation 1. See Appendix E.





NOTE: SEE APPENDIX E

FIGURE 15. RELATIONSHIP OF WET MU VALUE WITH RUBBER ACCUMULATION FOR ASPHALT PAVEMENTS



NOTE: SEE APPENDIX E

FIGURE 16. RELATIONSHIP OF WET MU VALUE WITH RUBBER ACCUMULATION FOR CONCRETE PAVEMENTS

2.6.4.2 Relationship to Aircraft Landings - It is reasonable to expect that rubber accumulation (and hence surface friction) should be related to the amount of use a runway receives, in terms of aircraft landings. Many factors affect the amount of rubber deposited on a runway during a landing, such as aircraft weight and type, landing speed, ambient temperature, pavement surface and tire material, loading and configuration. Since the landing speed and wheel loadings are generally similar for the classes of aircraft that account for most rubber deposition, rubber accumulation is a function of the number of wheel impacts which is in turn a function of aircraft landing weight. A simple common denominator was needed to express these factors for comparison with observed rates of rubber accumulation. The statistical analyses also show that the greatest correlation is with total landing weight for all aircraft heavier than 12,500 lbs. In this report, the runway utilization parameter is "aircraft landings", expressed in millions of pounds per year. Lighter aircraft are not included as their landing speeds and wheel loadings are generally much lower.

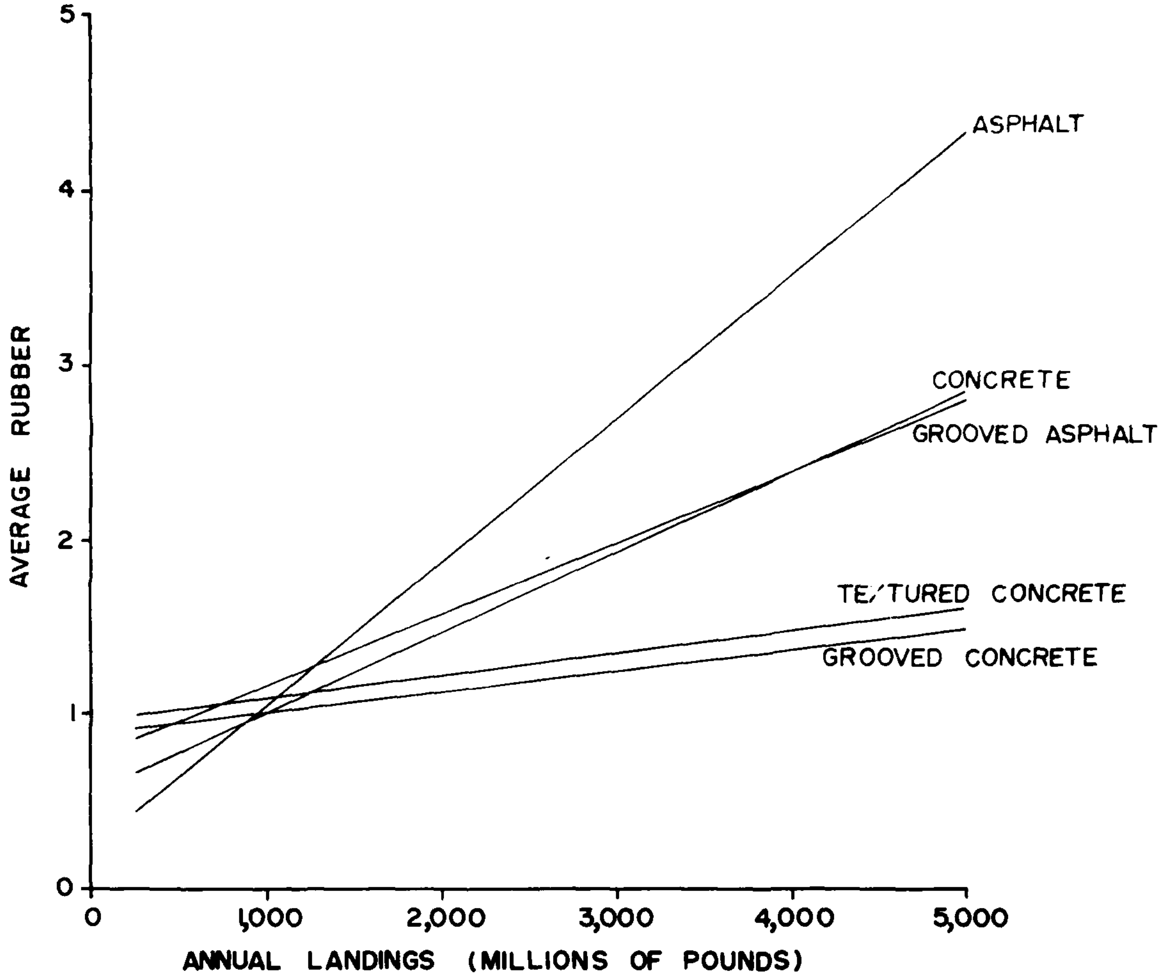
Numbers of landings for each aircraft type were obtained at every airport, and airport staff provided data or estimates of the percentage of total landings associated with each runway end. For each runway end, then, the annual landings are computed by multiplying the number of landings of each type of aircraft times the maximum landing weight of that type, and summing the results.

Relationships of various kinds were investigated, and it was found that different sorts of relationships best described runways which had never been subjected to rubber removal versus those which had.

Inspection of aircraft landings data sorted in rank order revealed that runway ends with landings less than 250 million lb/yr rarely have significant rubber accumulation. This is an important observation, as it indicates that certain factors must tend to remove or degrade rubber on runways; for otherwise even low usage runways would eventually accumulate rubber. Factors tending to remove or degrade rubber may include weathering, sunlight, microbial activity, snow removal activities (plowing, scraping and sanding) and sweeping.

Another observation is that very few runways with no record of rubber removal have aircraft landings greater than 5,000 million lb/yr. Further analysis of "never cleaned" runways revealed that rubber accumulation on such runways can be more accurately related to annual aircraft landings than to cumulative landings since the pavement surface was newly finished. This suggests that on these "never cleaned" (i.e., lower use) runways a steady state develops between rubber deposition and those factors tending to remove or degrade rubber.

The relationship to annual landings is shown in Figure 17 - Relationship of Average Rubber (2,000-foot) to Annual Landings for Runways Never Cleaned. To develop these relationships, only those runway ends with landings greater than 250 million lb/yr



NOTE: SEE APPENDIX E

FIGURE 17. RELATIONSHIP OF AVERAGE RUBBER (2000-FOOT) TO ANNUAL LANDINGS FOR RUNWAYS NEVER CLEANED

were analyzed. All pavement types have similar rubber accumulation at low usage rates (approximately 1,000 million lb/yr and less). The pavement types accumulate rubber differently, however, at usage rates above 1,000 million lb/yr. In this higher range, for a given rate of annual landings, asphalt runways generally have more rubber than concrete runways, and ungrooved runways have more rubber than grooved runways.

The measure of rubber accumulation used in the above analysis is a computed 2,000-foot average value. It is defined for each runway end as the area under the graph of rubber rating (on the zero to nine scale) versus distance, divided by 2,000 feet. The 2,000-foot distance is typical of the zone of rubber accumulation on runway ends. The average defined in this way allows valid comparison between different runways of the total accumulation of rubber.

The relationship between 2,000-foot average rubber and maximum 500-foot segment rubber is

$$R_{avg} = -0.22 + 0.73R_{max} \quad \text{(2)}$$

in which

R_{avg} = 2,000-foot average rubber rating for runway end;

and

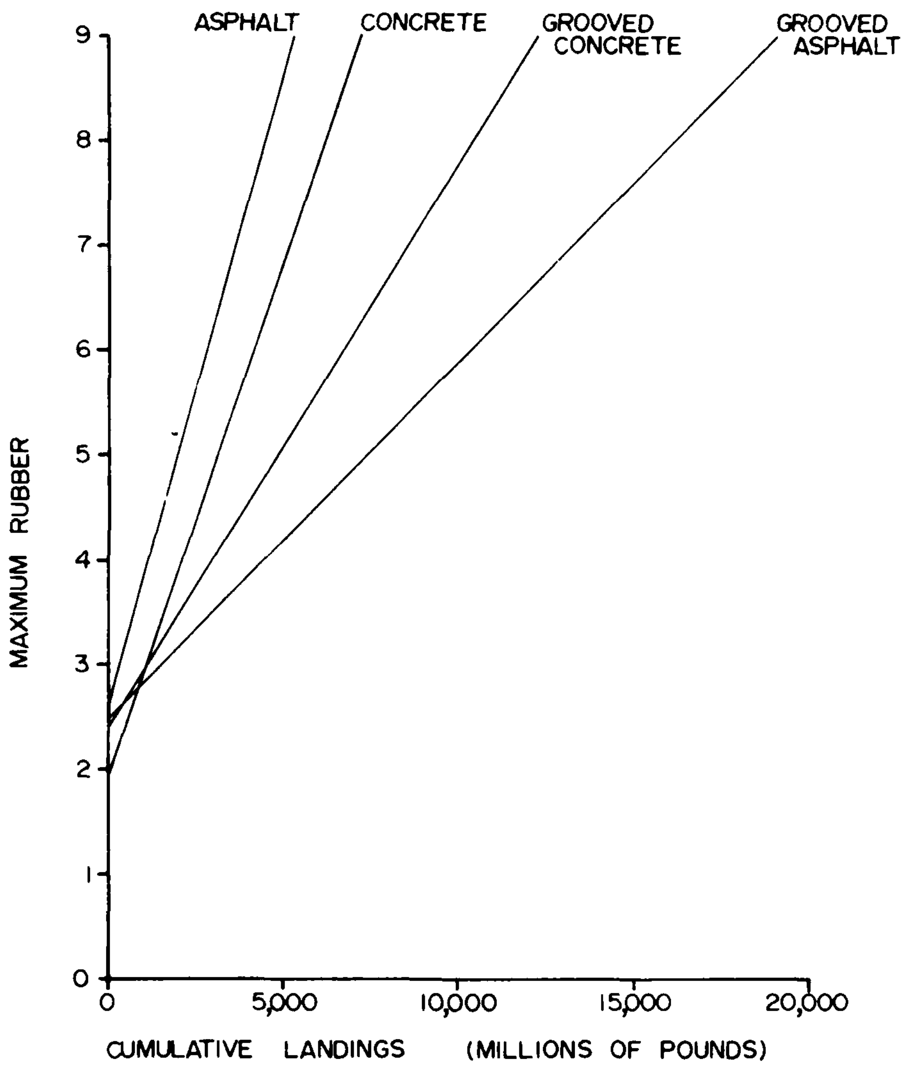
R_{max} = maximum 500-foot segment rubber rating on runway end.

For "never cleaned" runways, the statistical analysis achieved better results using average rubber rather than maximum rubber. However, maximum rubber is the more meaningful parameter, as it is the basis for prediction of the minimum 500-foot segment wet Mu value.

2.6.4.3 Effectiveness of Rubber Removal - Approximately 19 percent of all runways tested in the program had rubber removal during the program or within one year prior to initial testing. The cleaning method was in nearly all cases high pressure water. There were no instances of rubber removal on porous friction courses, chip seals or slurry seals during the program. It was usual to observe rubber accumulation on runways previously cleaned. In most cases some weeks or months had elapsed between the cleaning and the observation.

Runways having rubber removal include those with the highest usage rates. In terms of annual aircraft landings, a few runways exceed 15,000 million lb/yr. At the other extreme, approximately 30 percent of runways with rubber removal have annual landings below 1,000 million lb/yr.

In contrast to runways which did not have rubber removal, rubber accumulation on cleaned runways was more accurately related to cumulative landings since rubber removal than to annual



NOTE: SEE APPENDIX E

FIGURE 18. RELATIONSHIP OF MAXIMUM RUBBER (500-FOOT SEGMENT) TO CUMULATIVE LANDINGS SINCE RUBBER REMOVAL

landings. The relationship is illustrated in Figure 18 - Relationship of Maximum Rubber (500-foot segment) to Cumulative Landings Since Rubber Removal.

The regression lines in the figure correspond to equations of the following form:

$$R_{max} = c + k \cdot L \quad (3)$$

in which

R_{max} = maximum 500-foot segment rubber rating on runway end;

c = intercept constant, having units of rubber accumulation rating;

k = slope constant, having units of rubber rating per million lb of aircraft landings; and

L = cumulative aircraft landings on runway end, in million lb.

Table 7 - Regression Constants Relating Rubber Accumulation to Cumulative Landings Since Rubber Removal, presents the results of the regression analysis for Equation 3.

TABLE 7. REGRESSION CONSTANTS RELATING RUBBER ACCUMULATION TO CUMULATIVE LANDINGS SINCE RUBBER REMOVAL

Pavement Class	Intercept c	Slope k	Standard Error of k
Asphalt	2.6	0.0012	± 0.0006
Asphalt, Saw-Cut Grooved	2.5	0.00034	± 0.00013
Concrete	1.9	0.00098	± 0.00019
Concrete, Saw-Cut Grooved	2.4	0.00059	± 0.00008

The intercept constants in Table 7 provide a simple and direct measure of the effectiveness of rubber removal. The intercept constants are approximately 2-2.5, representing rubber accumulation to the degree that one-fourth of the pavement texture is filled or obliterated. This is a statistically derived estimate of the maximum 500-foot segment rubber rating to be found on a runway immediately after rubber removal. Since rubber removal decreases maximum rubber, the minimum wet Mu value is therefore increased.

The slope constants indicate the rate of rubber accumulation for each broad pavement classification. Note that the number of

cleaned runways was not large enough to allow a more detailed breakdown of pavement types for this analysis.

The slopes for ungrooved asphalt and ungrooved concrete are similar and indicate that an increase in cumulative landings of approximately 1,000 million lb causes a unit increase in the maximum rubber rating. The cumulative landings per unit rubber increase are roughly twice the above for grooved concrete and three times the above for grooved asphalt.

Thus grooved pavements accumulate less rubber for a given amount of usage than ungrooved pavements. This result may seem surprising, as casual observation of high rubber accumulation on grooved runways could easily lead one to the opposite conclusion. The paradox can be resolved by realizing that grooved runways tend to be runways with higher usage; the higher usage apparently more than compensates for the lower accumulation rates.

Note that in this analysis of cleaned runways, equally good statistical relationships were obtained for maximum rubber (R_{max}) and average rubber (R_{avg}). The results for maximum rubber are presented because they are more meaningful, in that they relate directly to minimum wet Mu values.

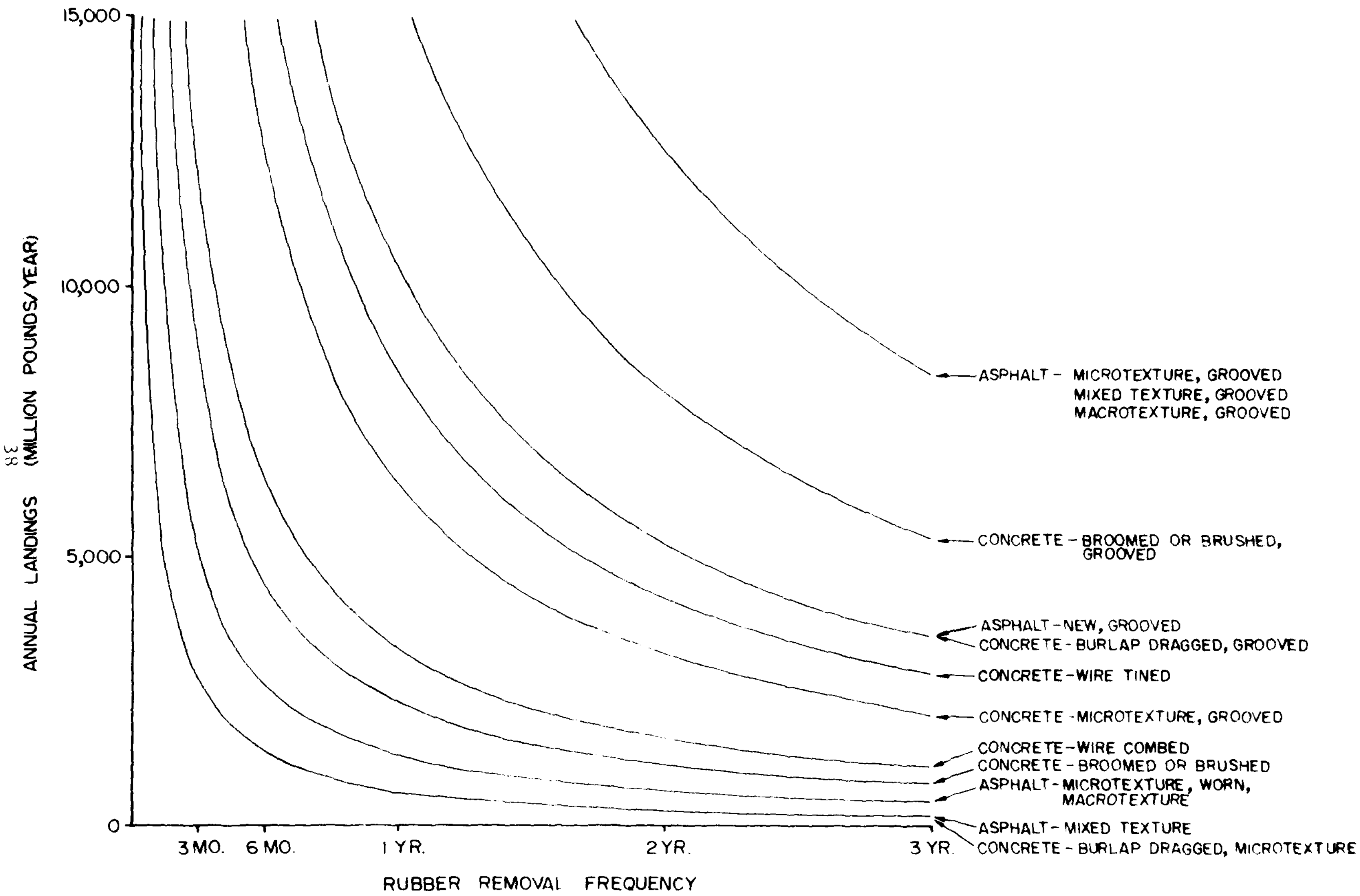
2.6.4.4 Guidelines for Rubber Removal Frequency - A useful summary of the relationships developed above for wet Mu value, rubber accumulation and aircraft landings is presented in Figure 19 - Rubber Removal Frequency for Various Pavement Types.

A joint FAA-USAF-NASA Runway Research Program was conducted from 1971 to 1974. Several turbo-jet aircraft and various friction measuring devices were tested on pavements with a wide range of slippery conditions. Based on these test results, a Mu value of 50 was selected as generally providing adequate runway surface friction.

Discussions with airport personnel confirm that a recommended minimum wet Mu value of 50 is reasonable to produce and provides adequate runway surface friction under most conditions. The recommended wet Mu value of 50 for the minimum 500-foot runway segment, as further discussed in Section 2.7, is assumed as the basis for Figure 19. The graph is not applicable to runways with low usage.

To use the figure for a given runway end, the annual aircraft landings in million lb/yr must first be known or estimated. (Refer to Section 2.6.4.2, second paragraph, for the procedure.) The corresponding rubber removal frequency can then be read directly from the appropriate curve. Sixteen out of the total of 28 distinguished pavement types have sufficient data to be represented in Figure 19. Certain curves depict more than one pavement type for which results are closely similar.

Figure 19 can be used to analyze surface treatment, resurfacing or construction alternatives for a runway which has or



NOTE: SEE APPENDIX E

FIGURE 19 RUBBER REMOVAL FREQUENCY FOR VARIOUS PAVEMENT TYPES

is expected to have high use. Alternatives might, for example, include saw-cut grooving the existing pavement, resurfacing with different material, resurfacing with the same material, resurfacing and grooving, or all new construction of various types. The capital cost of each alternative must be converted to an annual cost basis; to this is added the annual cost of rubber removal for each alternative, based on the required frequency from Figure 19. In this way, the total annual cost of alternatives can be compared directly and conveniently.

Figure 19 can also be used as a guideline in defining a specific maintenance program for a particular runway, but the figure should not be used alone for this purpose. Due to peculiarities of pavement construction, material and other factors which are not accounted for in the statistical analysis, individual runways will deviate from the curves shown in the figure. The figure may be thought of as indicating the required rubber removal frequency for the "average pavement" of each type. Maintenance of a particular runway should ultimately be based upon direct observation of rubber accumulation and measurement of surface friction.

2.6.5 Other Factors Related to Friction

2.6.5.1 Pavement Related Factors - On each runway tested, observations of pavement condition included ratings for structural distress and for joint or crack condition. These ratings were averaged for each 500-foot runway segment in the same manner as the rubber accumulation data, and the average values were included in initial multiple regression analyses.

It was found that runway friction measurement is not strongly related to pavement structural distress or to condition of joints or cracks, however, no evaluation of these factors as related to operational problems were made. This is not really a surprising result, as even severe structural distress (pavement cracking) and joint or crack condition (wide openings, not filled) imply a relatively small fractional loss of surface area. Incidentally, a strong statistical relationship does exist between structural distress and joint or crack condition. This also is not surprising, but neither is it very important to the consideration of runway friction.

Ruts and depressions on runways were also observed and quantified to identify possible areas of hydroplaning. Due to the nature of the testing during this program, hydroplaning due to ponding would not occur. Testing was not conducted under actual rainfall conditions since this would have introduced additional parameters and variability in the data, however, such testing is recommended.

2.6.5.2 Measurement Related Factors - Testing precision involves the precision of the measuring instrument and the test techniques employed. The Mu-Meter was used to measure surface friction on runway pavements in the National Runway Friction Measurement

Program. The device has been shown to be accurate and repeatable in many tests conducted in the U.S. and abroad. The device is accurately calibrated at the factory during assembly. Great care is exercised to insure accurate load cell and recorder response. Test techniques were established for the National Runway Friction Measurement Program which insured the maximum practical accuracy and repeatability. During the program the devices were subjected to a functional check before each run to insure that they were operating properly. The functional check involved operating the device on a portable test surface under controlled conditions, and it was required, according to the manufacturer's specifications, to [illegible] calibration reading within ± [illegible] of a reference Mu value [illegible]. Thus, the survey test results can be expected to be accurate to within ± [illegible]. This is the variation within the equipment and test procedures and should be considered as the precision of the survey test. This means that if all conditions on the runway are held constant, the same Mu-Meter will produce friction readings to within ± [illegible], regardless of the number of times the tests are run.

[illegible] to contribute additional variability. Pavement temperature and water temperature for the wet measurements were [illegible] significant. As airports were retested, it was [illegible] that one Mu-Meter was producing results as much as eight Mu values higher than those recorded during prior tests. A large portion of this difference was suspected to be the tires. Therefore, a series of tests were conducted with four sets of tires manufactured at different times in different facilities. The tests were conducted [illegible] Beaty of the Cranfield Institute [illegible] the FAA standard Mu-Meter under carefully [illegible] the National Runway Friction Measurement [illegible] parameters. The conclusion was that there is [illegible] difference among the various sets of tires. However, at the conclusion of the program, testing at Minneapolis with two different sets of tires on the same day with the same Mu-Meter, pavement and calibration reading showed another set of tires with results outside the variability discussed in the paragraph above. Because of this apparent variation in Mu-Meter readings [illegible] tires, further tests were conducted at the FAA Technical Center [illegible] all six Mu-Meters used during the program. The results of [illegible] tests show that all six Mu-Meters fall within [illegible] ± [illegible] Mu values (Appendix [illegible]).

[illegible] sets of tires were used in the National Program [illegible] two [illegible].4 percent) were out of tolerance for some [illegible], the impact on the data and conclusions in [illegible] would be very small. A Mu-Meter operator can preclude [illegible] of tire variability by following the calibration [illegible] of the [illegible] to AC 150/5320-12.

[illegible] the procedures employed, each airport was tested by different teams and equipment on different dates. In some instances as much as a year elapsed between successive measurements. In addition, variability would be introduced by slight differences in water distribution rates and displacement of

the Mu-Meter from the centerline during testing. Climatic conditions also affect the measurement of surface friction. These conditions may include air, pavement and water temperatures during testing and antecedent precipitation. These factors, as well as normal measurement variability, affected the measurement of friction between successive tests at an airport.

Extreme variability between successive measurements indicates the possibility that human error, equipment malfunction or other unaccounted factors have resulted in unrepresentative readings. For this reason, limits of acceptability were formulated for differences between successive measurements. See Section 2.3.6. These limits were used in the field for screening out unrepresentative data. In these cases, retesting was performed to eliminate human error and equipment malfunction. Approximately one percent of the 500-foot segment data fell outside the limits of acceptability for unaccounted factors. Note that the test precision, limits of acceptability of data and maintenance tolerances, while related, are actually different considerations. It is important to note that limits of acceptability are only applicable to the National Runway Friction Measurement Program and should not be construed as the precision of the Mu-Meter or as maintenance tolerances.

Certain measurement related factors have been successfully accounted for by statistical analysis. These factors are calibration reading, water temperature and pavement temperature. Briefly, the findings are as follows:

(1) To correct for the deviation of the calibration reading from the reference Mu value of 77, multiply the deviation (which is in the range -3 to +3) times 0.25 and subtract the result from the raw Mu data.

(2) The effect of water temperature is to decrease wet Mu values as water temperature increases, the rate of decrease being approximately 0.5 Mu value per degree Celsius.

(3) The effect of pavement temperature is opposed to that of water temperature, and there is approximately 0.2 Mu value increase per degree Celsius increase in pavement temperature.

Mu data can be adjusted for calibration and normalized to the reference temperature of 20°C according to the following formula:

$$M_{cr} = M_{raw} - 0.25C_d + 0.5T_w - 0.2T_p - 6.0 \quad \text{......... (4)}$$

in which

M_{cr} = wet Mu value adjusted for calibration and normalized to the reference temperature of 20°C;

M_{raw} = raw wet Mu value;

C_d = calibration deviation, defined as calibration reading minus 77 Mu value;

T_w = temperature of water used in the wet friction measurement, in degrees Celsius; and

T_p = pavement temperature, degrees Celsius.

The constant term, -6.0, arises from the temperature adjustment to 20°C. Note that when both T_w and T_p equal 20°C, all terms in Equation 4 to the right of C_d total to zero.

The data in this report were not adjusted since the adjustments are small and the various temperature and calibration values encountered tend to cancel each other. The equation is only an approximation because the data on which it is based includes many other factors. It is recommended that more accurate normalization factors be developed under controlled test conditions. The equation may be useful for a particular runway measured repeatedly to achieve a more precise measurement.

To sum up this discussion, a variety of extraneous factors impinge on the measurement of surface friction with the Mu-Meter. Certain of these factors can be accounted for quantitatively as in Equation 4. Mu data obtained in the program have yielded a rational and useful analysis of runway friction and thereby have proved their adequacy to the intended purpose.

2.7 MODIFICATIONS IN ADVISORY CIRCULAR 150/5320-12

Experience during the National Runway Friction Measurement Program has shown that the Mu-Meter is an effective friction measurement device embodying an excellent physical principle for measuring runway friction. Continuous recording of measurements allows the airport sponsor to analyze and quantify specific areas in detail as well as the entire runway surface. Several changes in the Mu-Meter since its conception have improved the usefulness of the device without affecting the basic design principles. The capability of automatically recording 500-foot segments on the strip chart used extensively during the program, is one useful change. A list of suggested further modifications for improved ease of operation, reduction and simplification of maintenance and improvement in data collection was transmitted to the Mu-Meter manufacturer for consideration in future modifications.

Throughout this program, airport sponsors were generally aware of low surface friction when informed that a portion of their runway was below the recommended minimum Mu value of 50. Of the 491 runways tested, 122 (24.8%) had wet Mu values less than 50 on at least one 500-foot segment on their final test. However, only 1900 (4.5%) of the 42,000 segments had wet Mu values less than 50. Of the 122 runways with low segments, 64 runways (52.5%) had wet Mu values less than 50 for less than 1000 feet.

The following modifications to A/C 150/5320-12 therefore reflect a minimum Mu value of 50. The primary purpose of this report is to establish simplified guidance and criteria for airport operators to maintain runways at adequate friction levels. Further investigations of actual aircraft performance will, in the future, provide additional data.

It should be noted that throughout the program and this report, Mu values are multiplied by 100 and therefore range from 0 to 100. For use in the following recommendations for modifications to A/C 150/5320-12, Mu values are expressed from a range of 0.00 to 1.00. Thus, the recommended minimum value of 50 is expressed in these recommendations as 0.50.

During Phase I of the National Runway Friction Measurement Program, an evaluation of different water depths for wet friction measurements was accomplished. It was determined that a water depth of 1.0 mm (0.04 inches) was needed to fill the voids of the pavement texture. A hydrologic study (Appendix H) was performed as part of this investigation and confirmed that the application of 1.0 mm (0.04 inches) of water in front of the Mu-Meter friction measuring tires would provide a better test to accomplish the objectives of the program. A number of other studies, including data developed by the Texas Transportation Institute, ICAO recommendations and literature values support this conclusion. Also, 1.0 mm (0.04 inches) depth of water better represents conditions encountered on runways during rainfall throughout the contiguous 48 states. Experience indicates that more meaningful data were collected using this water depth.

In the Advisory Circular modifications described below, the Suggested Schedule for Friction Surveys is based on Figure 19 - Rubber Removal Frequency for Pavement Types. All of the scheduled turbo-jet runways would be checked at least annually. Approximately 15 runways would need testing more than once per month.

The following modifications are suggested as a result of the engineering analysis as well as the extensive experience accumulated during this program.

1.a. Replace existing paragraph with the following:

"Texturing Techniques for Asphaltic Concrete Pavements. Surface textures of newly constructed asphaltic concrete pavements are generally quite smooth. This is due to the effort required during construction by the rolling equipment to achieve the required compaction and density. However, several methods are available to improve texture and surface friction in asphaltic concrete pavements. These include saw-cut grooves, porous friction course, chip seals and skid-resistant aggregate slurry seals."

1.b.(1) Add to end of existing paragraph:

"Efforts should be made to improve the texture of plastic grooved concrete pavements in the areas between the grooves."

1.c.(1) Change second sentence:

"Experience has shown that uncontaminated concrete pavements that have an average texture depth of 0.015 inches provide good surface friction."

3.c. Change "200 yards" to "500 feet."

Figure 2-1: A new photo with an updated self-watering system should be used to avoid confusing new users of the equipment.

3.c.(1) Replace the first sentence with the following:

"Frequent checks of the Mu-Meter's functions and calibration should be made by performing test runs with self-watering equipment at a constant speed of 40 mph over clean, untrafficked pavement."

3.c.(4) Replace the fourth sentence with the following:

"The total flow rate of 88 gallons/minute (44 gallons/minute on each side) is required to obtain a water depth of 0.04 inches for a tow vehicle speed of 40 mph."

3.c.(4)a. Replace the second sentence with the following:

"For consistent measurement of wet runway pavement surfaces, it is suggested that the airport sponsor use self-watering equipment."

3.c.(4)b. Replace second and third sentences with the following:

"It takes 150 gallons of water to test 6000 feet of runway pavement. The weight of 150 gallons of water is 1250 pounds."

4. Replace the existing paragraph with the following:

"MEASUREMENT PARAMETERS. Conditions which influence surface friction characteristics of wet pavement surfaces are pavement texture, contaminants (especially rubber accumulation) and pavement abnormalities. The airport sponsor should evaluate each of these conditions by the following parameters."

4.a. Delete paragraph.

4.a.(1) Delete paragraph.

4.a.(2) Delete paragraph.

4.b. Replace the existing paragraph with the following:

"Contaminants. Surface friction characteristics of runway pavements may be significantly affected by contaminant accumulation over a period of time. One of the main problems facing the airport sponsor concerning the condition of runway pavement surfaces is rubber accumulation. Suggested methods for cleaning are given in Chapter 4. Other corrective action given in Chapter 3 may be considered to improve the friction characteristics of a contaminated runway pavement surface. The following parameter is given to assist the airport sponsor in making the decision on when it is necessary to remove contaminants from the runway pavement surface."

4.b.(1) Replace existing paragraph with the following:

"When the AVERAGED MU VALUE within the contaminated area is less than 50 for a distance of 500 feet or more, corrective action should be performed on the entire contaminated area."

4.b.(2) Delete paragraph.

4.b.(3) Delete paragraph.

4.c. Delete paragraph. It is recommended that an alternate paragraph be developed.

4.c.(1) Delete paragraph.

4.d. Change section to 4.c.

4.d. Replace the third sentence with the following:

"For this reason the surface friction should be determined under actual rainfall conditions through the surface areas subject to ponding."

4.d.(1) Replace first sentence with the following:

"When the AVERAGED MU VALUE within a ponded area is less than 0.50, corrective action should be taken."

4.e. Change paragraph to 4.a.

4.e. Replace paragraph as follows:

"Surface Treatment. A basic determinant of surface friction is the texture depth of a runway pavement surface. An increase in texture depth will produce a corresponding increase in surface friction. Suggested methods for improving texture are given in Chapter 3 and include saw-cut grooving, porous friction course, chip seals, and aggregate seal coats and plastic texturing of concrete pavements. The following parameter is given to assist the airport sponsor in determining when corrective action is necessary.

(1) When the AVERAGED MU VALUE of the pavement is less than 50, for a distance of 500 feet or more, corrective action should be performed on the runway pavement surface."

5.a. Replace "limits of rubber deposits" with "limits and degree of rubber accumulation."

5.a.(1) Add the following paragraph:

"The extent and degree of rubber accumulation should be determined in areas of rubber contamination. The degree of rubber accumulation should be rated from zero (essentially no rubber accumulation) to nine (essentially complete obliteration of pavement texture by rubber). Experience has shown that visual observations alone are insufficient for making an accurate determination of rubber accumulation, and the pavement surface must actually be felt."

5.b. Replace existing paragraph with the following:

"Self-watering devices used with Mu-Meters require 300 gallons (2500 pounds) of water to cover approximately 12,000 feet of runway. Water is carried in the tow vehicle in either flexible or rigid tanks."

5.c. Replace the second and third sentence with the following:

"A 300-gallon system will usually allow testing of a 13,000-foot runway because 500 feet is allowed for acceleration and deceleration of the tow vehicle. Tests in both directions can be performed on a 7,000-foot runway with a 300-gallon water tank."

5.d.(1) Change "10 feet from" to "10 feet to the right of."
Add to existing paragraph:

"Additional test runs in rubber areas can be performed at different distances from the centerline to determine the transverse extent of low surface friction due to rubber."

5.d.(2) Delete paragraph.

5.d.(3) Replace first sentence with the following:

"These test runs are used to determine the surface friction of runway pavements."

5.d.(4) Change to 5.d.(2).
Delete last sentence.

5.d.(5) Change to 5.d.(4).
Change the third sentence from "relative loss of friction" to "friction characteristics".
Change "4d(1)" to "4c(1)."

5.d.(6) Change to 5.d.(5).
Change "4c(1)" to "4b."

6.-6.d.(3) Replace entire existing section with the following:

"Data Acquisition. The strip chart provides a permanent record of the Mu values on a particular runway surface. Identification of significant field observations affecting the Mu values should be made directly on the strip chart. The strip chart obtained in subsequent surveys can then be compared by the airport sponsor with previous test runs. The airport sponsor should emphasize to the test personnel the importance of conducting the survey at the same location as previous test runs, so proper comparisons can be made.

a. Pertinent Test Information. At the beginning of each test run the strip chart should be identified with the following information:

(1) Airport Designator or Name
(2) Runway Designation (end from which test began)
(3) Survey Date
(4) Survey Time (in 24 hours)
(5) Survey Test Personnel
(6) Water Temperature
(7) Pavement Temperature
(8) Type of Test (calibration, dry, wet)

b. Interpretation of Data. Parameters for interpretation of data are provided in paragraph 4."

9.b. Change the second sentence to the following:

"Water drainage and skid resistance for asphaltic concrete pavements can be improved by addition of saw-cut grooves, a porous friction course, addition of a chip seal or by addition of a skid resistant aggregate slurry seal as an interim measure.
Delete the third sentence.

9.b.(3) Change to 9.b.(4).

Add the following section:

"9.b.(3) Chip Seal. Improvement of surface friction can be achieved by constructing a chip seal. Some chip seals have been constructed with an asphalt rubber mix."

Specific FAA specifications on chip seal should be added concerning asphalt mix, size and composition of aggregate and preparation and construction methods to be used.

13. Replace existing paragraph with the following:

"Suggested Maintenance Schedule. For any maintenance program to succeed, runways should be inspected frequently. Observations noted during visual inspections of pavement surfaces will help determine if a friction survey is required. Runways which have Mu values less than 0.50 on a previous test should be tested more frequently than suggested below. Table 5-1 suggests a schedule for friction surveys based on the annual landing weight of the most heavily used runway. The annual landing weight may be found by first finding the total number of annual landings of each type of aircraft landing at an airport. The annual landings of each type of aircraft should then be multiplied by the corresponding maximum landing weight as given in AC 150/5325-5B. The sum of these values will produce the annual landing weight at the airport. The annual landing weight should then be multiplied by the percentage of landings on the most heavily used runway end. The resulting runway end annual landing weight should be used in Table 5-1. It is suggested that the airport sponsor test all runways at the airport each time a survey is performed."

TABLE 5-1. Replace existing table with the following:

SUGGESTED SCHEDULE FOR FRICTION SURVEYS

Runway End Annual Landing Weight (million pounds/year)	Frequency of Friction Surveys: Ungrooved Pavements	Frequency of Friction Surveys: Porous Friction Course Saw-Cut Grooved Wire Tined
Less than 1000	Annual	Annual
1000-2000	6 months	Annual
2000-4000	3 months	Annual
4000-8000	1 month	6 months
8000 and above	Monthly or more often as required	6 months

3. CONCLUSIONS

3.1 PRIMARY CONCLUSIONS

1. Rubber accumulation on runway pavements profoundly affects surface friction. These effects have been quantified for various pavement types and range from 1.6 to 6.9 wet Mu value decrease per unit increase in rubber accumulation rating.

2. Rubber removal improves runway surface friction characteristics.

3. Saw-cut grooving improves drainage and reduces hydroplaning potential in addition to improving runway surface friction. The friction enhancement due to grooving is greater in areas of rubber accumulation than in uncontaminated areas.

4. For low-use runways, a reasonable basis for comparing and ranking the surface friction characteristics of various pavement types is provided by mean wet Mu values for uncontaminated areas. (See Table 4 and Figure 9.)

5. For high-use runways, guidelines have been developed for rubber removal frequency dependent on pavement type and annual landings. (See Figure 19.) These guidelines can be used in projecting and comparing annual costs of runway construction, resurfacing or pavement treatment alternatives, as well as in guiding maintenance of existing runways.

6. The Airport Survey Reports produced for each of the 268 airports after each testing provided timely input for airport maintenance purposes.

7. The purpose and objectives of the National Runway Friction Measurement Program were achieved. Mu-Meter measurements and Pavement Condition Survey data obtained in this program have yielded a rational and useful analysis of runway friction.

8. The Mu-Meter is a rapid and effective device for measuring surface friction when operated in accordance with the manufacturer's instructions.

9. A Mu value of 50 or greater has long been generally accepted as providing adequate runway friction under most operating conditions. This program did not disclose data to support any other value. It must be understood that as friction decreases the relative safety decreases, but it is gradual and time-related, that is, when the Mu value decreases from 50 to 49 the pavement does not go from totally adequate to totally inadequate.

3.2 CONCLUSIONS REGARDING PAVEMENT CHARACTERISTICS

10. The ranking of pavement types on the basis of mean texture depth closely follows the surface friction ranking. However, measurements of friction rather than texture are a preferable basis for planning routine runway maintenance.

11. Texture depth and rate of change in texture depth increases with pavement age. The increase rate varies from less than 0.4 thousandths of an inch per year during the first year to more than four thousandths of an inch per year after 10 years for asphalt pavements, and apparently somewhat lower for concrete.

3.3 CONCLUSIONS REGARDING PAVEMENT GROOVING

12. The benefits of improved drainage and enhancement of friction due to grooving are greater for narrower groove spacing. A one-inch difference in spacing causes approximately a five Mu value difference in surface friction over the range from 1¼ to 3 inches encountered in the program.

13. Groove deterioration produces a small effect on surface friction.

14. The rate of rubber accumulation on grooved runways is less than on ungrooved runways with the same level of usage.

3.4 CONCLUSIONS REGARDING RUBBER ACCUMULATION AND REMOVAL

15. Rubber removal reduces the maximum 500-foot runway segment rubber rating to approximately 2-2.5, corresponding to 20-25 percent texture obliteration or filling with rubber.

16. Rubber accumulation can be related to aircraft landings expressed as the summation of total landing weight on the runway end.

17. For low-use runways, rubber accumulation is dependent on annual aircraft landings (i.e., usage rate) and pavement type according to the scheme:

Annual Landings	Rubber Accumulation
Below 250 million lb/yr	Essentially zero for all pavement types
From 250 to 1,000 million lb/yr	Very low for all pavement types
From 1,000 to 5,000 million lb/yr	Linearly dependent on annual landings, with different slopes for different pavements

18. For high-use runways (having rubber removal), rubber accumulation is linearly dependent on cumulative aircraft landings since rubber removal (i.e., cumulative usage), with different slopes for different pavements.

19. Field observation indicates that it is difficult to remove rubber from the porous friction course pavements.

3.5 OTHER CONCLUSIONS

20. Wet Mu values can be corrected for calibration and adjusted to the reference temperature 20°C. (See Equation 4.)

21. Personnel can be adequately trained to operate and maintain the Mu-Meter to provide friction data for engineering and maintenance purposes provided they operate the equipment regularly.

22. The program has successfully demonstrated that personnel can be trained to observe rubber accumulation and other runway conditions on consistent and correlatable scales.

23. The large data base resulting from this program can, with relatively small additional data collection, be used to determine long-term maintenance and pavement requirements nationally.

24. Future analysis of the stereo photos could provide significant findings on the charactersitics of aggregate microtexture and other factors which produce desirable friction.

4. RECOMMENDATIONS

The National Runway Friction Measurement Program has resulted in the following recommendations:

1. Pavement types having high surface friction, as identified in Figure 9, should be considered in the planning and design of new runway surfaces, particularly for low-use runways.

2. The guidelines for rubber removal frequency, as contained in Figure 19, should be used in planning and design of new runway surfaces and as a maintenance guideline, for high-use runways. Specific scheduling of rubber removal for an existing runway should ultimately be based on direct observation of rubber accumulation and measurement of surface friction.

3. The rating system used in this program for rubber accumulation should be formalized and promulgated for use by airport maintenance personnel.

4. Porous friction course, saw-cut grooving or other surface treatments should be considered for existing runway pavements with low surface friction.

5. The standard groove spacing (1¼ inches) should continue to be used.

6. The large data base from this program should be used to determine long-term runway maintenance and pavement requirements on a national basis.

7. Programs should be designed and implemented to define relationships of runway friction to environmental factors (e.g., actual rainfall conditions) and aircraft performance.

8. Advisory Circular 150/5320-12 should be updated with modifications outlined in Section 2.7.

9. Studies should be performed to evaluate rubber accumulation data and rubber removal effectiveness on porous friction course pavements.

APPENDIX A

National Runway Friction Measurement Program
Survey Dates

APPENDIX A - SURVEY DATES

CITY	ST	DES	AIRPORT NAME	TEST STARTING DATES			[illegible]
			CENTRAL REGION				
CEDAR RAPIDS	IA	CID-CEDAR RAPIDS MUNICIPAL AIRPORT		07/22/79	11/13/79		9, 1[illegible]
COLUMBIA	MO	COU-COLUMBIA REGIONAL AIRPORT		07/14/79	10/23/79	03/24/80	2
DES MOINES	IA	DSM-DES MOINES MUNICIPAL AIRPORT		07/21/79	11/14/79	04/24/80	5, [illegible]
DUBUQUE	IA	DBQ-DUBUQUE MUNICIPAL AIRPORT		07/23/79	11/11/79	04/21/80	[illegible]
FORT DODGE	IA	FOD-FORT DODGE MUNICIPAL AIRPORT		08/08/79	11/08/79		6
GRAND ISLAND	NE	GRI-HALL COUNTY REGIONAL AIRPORT		08/16/79	12/04/79	08/18/80	15, 4, 1[illegible]
JOPLIN	MO	JLN-JOPLIN MUNICIPAL AIRPORT		07/09/79	11/09/79	03/21/80	13
KANSAS CITY	MO	MCI-KANSAS CITY INT'L AIRPORT		07/18/79	10/24/79	03/19/80	9, 1
LINCOLN	NE	LNK-LINCOLN MUNICIPAL AIRPORT		08/13/79	11/18/79	08/19/80	[illegible], 1[illegible], 14
MANHATTAN	KS	MHK-MANHATTAN MUNICIPAL AIRPORT		03/15/80	08/22/80		3
MASON CITY	IA	MCW-MASON CITY AIRPORT		08/07/79	11/09/79		17, 12
OMAHA	NE	OMA-EPPLEY AIRFIELD		08/11/79	11/17/79	08/21/10	17, 14B
SALINA	KS	SLN-SALINA MUNICIPAL AIRPORT		08/18/79	11/05/79	08/23/10	1[illegible], 17
SIOUX CITY	IA	SUX-SIOUX CITY MUNICIPAL AIRPORT		08/09/79	11/06/79	08/22/10	4, 13, 17
SPRINGFIELD	MO	SGF-SPRINGFIELD MUNICIPAL AIRPORT		07/11/79	11/10/79	03/22/10	1, 15
ST LOUIS	MO	STL-LAMBERT ST LOUIS INT'L ARPT		07/13/79	10/20/79	08/28/10	6, 12B, 12[illegible]
TOPEKA	KS	FOE-FORBES FIELD		08/22/79	11/03/79	08/25/10	3, 13
WATERLOO	IA	ALO-WATERLOO MUNICIPAL AIRPORT		07/25/79	11/13/79	04/22/80	12, 6, 18
WICHITA	KS	ICT-WICHITA MID-CONTINENT AIRPORT		08/21/79	11/07/79	08/21/80	18, 14, [illegible]
			EASTERN REGION				
ALBANY	NY	ALB-ALBANY COUNTY AIRPORT		06/20/79	09/26/79	05/23/80	1, 1[illegible]
ALLENTOWN	PA	ABE-ALLENTOWN-BETHLEHEM-EASTON ARPT		05/22/79	08/22/79	04/10/80	13, 6
BALTIMORE	MD	BWI-BALTIMORE WASHINGTON INT'L ARPT		05/15/79	08/18/79	03/20/80	4, 15B, [illegible]
BINGHAMTON	NY	BGM-BROOME COUNTY AIRPORT		05/19/79	08/21/79	05/24/80	16, 10
BUFFALO	NY	BUF-GREATER BUFFALO INT'L AIRPORT		05/25/79	08/11/79	07/15/80	5, 14
CHARLESTON	WV	CRW-KANAWHA COUNTY AIRPORT		06/12/79	08/17/79	07/22/80	5
CHARLOTTES-VILLE	VA	CHO-CHARLOTTESVILLE ALBEMARLE ARPT		06/17/79	08/22/79	03/16/80	3
ELMIRA	NY	ELM-CHEMUNG COUNTY AIRPORT		05/14/79	07/26/79	07/08/80	10, 6
ERIE	PA	ERI-ERIE INTERNATIONAL AIRPORT		05/24/79	08/12/79	07/16/80	6
HUNTINGTON	WV	HTS-TRI STATE WALKER-LONG FIELD		06/11/79	08/16/79		12

CITY	ST	DES	AIRPORT NAME	TEST STARTING DATES			RWY(S)
ISLIP	NY	ISP-LONG ISLAND MACARTHUR AIRPORT	06/16/79	09/12/79	04/16/80	6, 10, 15R
ITHICA	NY	ITH-TOMPKINS COUNTY AIRPORT	05/16/79	07/25/79	07/09/80	14
LEWISBURG	WV	LWB-GREENBRIER VALLEY AIRPORT	06/13/79	08/18/79	03/15/80	22
LYNCHBURG	VA	LYH-LYNCHBURG MUNICIPAL AIRPORT	06/15/79	08/21/79	03/12/80	3
MIDDLETOWN	PA	MDT-HARRISBURG INT'L AIRPORT	05/17/79	08/20/79	03/22/80	13
NEW YORK	NY	JFK-JOHN F KENNEDY INT'L AIRPORT	09/23/78	09/21/79	04/14/80	4L, 4R, 13L, 13R
NEW YORK	NY	LGA-LAGUARDIA AIRPORT	06/13/79	09/11/79	04/13/80	13, 4
NEWARK	NJ	EWR-NEWARK INTERNATIONAL AIRPORT	06/09/79	08/28/79	04/12/80	4L, [illegible], 4R
NEWPORT NEWS	VA	PHF-PATRICK HENRY INT'L AIRPORT	06/20/79	08/26/79	03/09/80	7, 2
NORFOLK	VA	ORF-NORFOLK INTERNATIONAL AIRPORT	06/22/79	08/28/79	03/08/80	23
PARKERSBURG	WV	PKB-WOOD COUNTY AIRPORT	06/07/79	08/15/79	07/21/80	3
PHILADELPHIA	PA	PHL-PHILADELPHIA INT'L AIRPORT	06/06/79	08/25/79	03/25/80	17, 9R, 9L
PITTSBURGH	PA	PIT-GREATER PITTSBURGH INT'L ARPT	06/09/79	08/14/79	07/19/80	10R, 10C, 10L, 14
RICHMOND	VA	RIC-RICHARD EVELYN BYRD INT'L ARPT	06/18/79	08/24/79	03/11/80	15, 6, 2
ROANOKE	VA	ROA-ROANOKE MUNICIPAL AIRPORT	06/14/79	08/19/79	03/12/80	15, 5
ROCHESTER	NY	ROC-ROCHESTER MONROE CO AIRPORT	05/19/79	08/09/79	07/11/80	10, 4
SYRACUSE	NY	SYR-SYRACUSE-HANCOCK INT'L AIRPORT	05/18/79	07/24/79	07/10/80	10, 14
TRENTON	NJ	TTN-MERCER COUNTY AIRPORT	06/09/79	08/26/79	03/23/80	16, 6
WASHINGTON DC	VA	DCA-WASHINGTON NATIONAL AIRPORT	06/23/79	09/11/79	03/20/80	15, 18
WASHINGTON (DULLES)	VA	IAD-DULLES INTERNATIONAL AIRPORT	05/09/79	08/16/79	03/18/80	1R, 1L, [illegible]
WHITE PLAINS	NY	HPN-WESTCHESTER COUNTY AIRPORT	06/18/79	09/23/79	04/18/80	16
WILKES-BARRE/ SCRATON	NY	AVP-WILKES-BARRE/SCRATON INT'L APT	05/18/79	08/21/79	05/24/80	4
			GREAT LAKES REGION				
AKRON	OH	CAK-AKRON-CANTON REGIONAL AIRPORT	07/11/79	09/15/79		[illegible]
ALPENA	MI	APN-PHELPS COLLINS AIRPORT	08/11/79	10/10/79	08/15/80	[illegible]
BLOOMINGTON	IL	BMI-BLOOMINGTON-NORMAL AIRPORT	06/07/79	09/11/79	04/16/80	11
CHAMPAIGN-URBANA	IL	CMI-UNIV OF ILLINOIS-WILLARD ARPT	06/14/79	09/18/79	[illegible]	[illegible]
CHICAGO	IL	ORD-CHICAGO O'HARE INT'L AIRPORT	07/05/79	09/26/79	[illegible]	9L, 9R, 4L, 4R, 14R, 14L
CHICAGO	IL	MDW-MIDWAY AIRPORT	07/08/79	10/10/79	[illegible]	[illegible], 4R
CLEVELAND	OH	CLE-CLEVELAND HOPKINS INT'L ARPT	07/09/79	09/17/79	08/07/80	5R, 5L, 18R, 10L

CITY	ST	DES	AIRPORT NAME	TEST STARTING DATES			RWY(S)
COLUMBUS	OH	CMH-PORT COLUMBUS INT'L AIRPORT	07/13/79	09/21/79	07/26/80	10L, 10R
CUYAHOGA CO	OH	CGF-CUYAHOGA COUNTY AIRPORT	09/19/79			5
DAYTON	OH	DAY-COX DAYTON INT'L AIRPORT	07/14/79	09/22/79	07/24/80	18, 6R, 6L
DECATUR	IL	DEC-DECATUR AIRPORT	06/12/79	09/16/79	04/11/80	12, 18, 6
DETROIT	MI	DTW-DETROIT METRO WAYNE CO ARPT	07/18/79	09/26/79	08/10/80	3L, 3C, 3R, 9
DULUTH	MN	DLH-DULUTH INTERNATIONAL AIRPORT	06/24/79	10/10/79	06/24/80	9, 3
EAU CLAIRE	WI	EAU-EAU CLAIRE COUNTY AIRPORT	06/18/79	10/05/79		4
ESCANABA	MI	ESC-DELTA COUNTY AIRPORT	05/16/79	08/18/79	08/19/80	9
EVANSVILLE	IN	EVV-EVANSVILLE DRESS REGIONAL ARPT	07/21/79	10/21/79	03/15/80	4, 18
FLINT	MI	FNT-FLINT BISHOP INT'L AIRPORT	07/20/79	09/28/79	08/12/80	18, 9
FORT WAYNE	IN	FWA-FORT WAYNE MUNICIPAL AIRPORT	06/18/79	09/24/79	07/25/80	9, 4, 13
GRAND RAPIDS	MI	GRR-KENT COUNTY INT'L AIRPORT	07/26/79	10/15/79	08/12/80	8R
GREEN BAY	WI	GRB-AUSTIN STRAUBEL FIELD	06/12/79	08/22/79	08/27/80	6R, 18
HANCOCK	MI	CMX-HOUGHTON COUNTY MEMORIAL ARPT	05/21/79	08/20/79	08/20/80	13, 7
HIBBING	MN	HIB-CHISHOLM-HIBBING AIRPORT	06/25/79	10/12/79	06/24/80	13
INDIANAPOLIS	IN	IND-INDIANAPOLIS INT'L AIRPORT	06/16/79	09/22/79	07/24/80	4L, 13
INT'L FALLS	MN	INL-INTERNATIONAL FALLS INT'L ARPT	06/26/79	10/11/79	06/23/80	13
JANESVILLE	WI	JVL-ROCK COUNTY AIRPORT	06/10/79	08/25/79	08/21/80	4, 13
KALAMAZOO	MI	AZO-KALAMAZOO MUNICIPAL AIRPORT	07/26/79	10/18/79	07/27/80	17
LACROSSE	WI	LSE-LACROSSE MUNICIPAL AIRPORT	06/16/79	09/16/79	08/29/80	13, 3, 18
LANSING	MI	LAN-CAPITAL CITY AIRPORT	07/24/79	10/16/79	07/27/80	9R, 6
MADISON	WI	MSN-DANE COUNTY AIRPORT-TRUAX FIELD	06/12/79	10/04/79	08/22/80	13, 18
MARION	IL	MWA-WILLIAMSON COUNTY AIRPORT	07/10/79	10/11/79	03/14/80	2
MILWAUKEE	WI	MKE-GENERAL MITCHELL FIELD	06/07/79	08/26/79	08/25/80	1L, 13, 7R
MINNEAPOLIS	MN	MSP-MPLS-ST PAUL INT'L AIRPORT	06/21/79	10/03/79	08/27/80	11R, 11L, 4
MOLINE	IL	MLI-QUAD-CITY AIRPORT	06/03/79	08/26/79	05/14/80	9, 12
MOSINEE	WI	CWA-CENTRAL WISCONSIN AIRPORT	06/15/79	10/04/79	08/23/80	8, 17
MUSKEGON	MI	MKG-MUSKEGON COUNTY AIRPORT	08/08/79	10/14/79	08/12/80	5, 14
OSHKOSH	WI	OSH-WITTMAN FIELD AIRPORT	05/25/79	08/23/79	08/28/80	9, 18
PELLSTON	MI	PLN-EMMET COUNTY AIRPORT	05/14/79	08/15/79	08/16/80	5, 14
PEORIA	IL	PIA-GREATER PEORIA AIRPORT	06/05/79	08/27/79	04/16/80	12, 4
QUINCY	IL	UIN-BALDWIN FIELD	06/08/79	09/13/79	05/09/80	17, 13, 3
RHINELANDER	WI	RHI-RHINELANDER ONEIDA CO ARPT	06/13/79	08/22/80		5, 9
ROCHESTER	MN	RST-ROCHESTER MUNICIPAL AIRPORT	06/19/79	09/17/79	08/28/80	2, 13
ROCKFORD	IL	RFD-GREATER ROCKFORD AIRPORT	06/01/79	08/24/79	08/20/80	18, 6
SAGINAW	MI	MBS-TRI-CITY AIRPORT	07/23/79	10/09/79	08/13/80	14, 5
SAULT ST MARIE	MI	CIU-CHIPPEWA COUNTY INT'L AIRPORT	05/18/79	08/16/79	08/18/80	15

CITY	ST	DES AIRPORT NAME	TEST STARTING DATES			RWY(S)
SOUTH BEND	IN	SBN-MICHIANA REGIONAL AIRPORT	06/20/79	09/25/79	08/14/80	9
SPRINGFIELD	IL	SPI-CAPITOL AIRPORT	06/09/79	09/15/79	05/08/80	12, 4, 18
TOLEDO	OH	TOL-TOLEDO EXPRESS AIRPORT	07/17/79	09/24/79	08/09/80	16, 7
TRAVERSE CITY	MI	TVC-CHERRY CAPITAL AIRPORT	08/14/79	10/12/79	08/14/80	18, 10
YOUNGSTOWN	OH	YNG-YOUNGSTOWN MUNICIPAL AIRPORT	09/12/79	07/17/80		14, 5
		NEW ENGLAND REGION				
BANGOR	ME	BGR-BANGOR INTERNATIONAL AIRPORT	07/18/79	10/17/79	05/20/80	15
BOSTON	MA	BOS-BOSTON-LOGAN INT'L AIRPORT	07/12/79	10/09/79	04/25/80	4L, 4R, 9, 15R
BURLINGTON	VT	BTV-BURLINGTON INT'L AIRPORT	07/22/78	10/18/79	05/22/80	15
MANCHESTER	NH	MHT-MANCHESTER AIRPORT	07/14/79	10/13/79	05/17/80	17, 6
NEW HAVEN	CN	HVN-TWEED NEW HAVEN AIRPORT	06/20/79	09/24/79	04/19/80	2
PORTLAND	ME	PWM-PORTLAND INT'L JETPORT	07/17/79	10/15/79	05/19/80	11
PRESQUE ISLE	ME	PQI-NORTHERN MAINE REGIONAL ARPT	07/19/79			1, 10
PROVIDENCE	RI	PVD-T F GREEN STATE AIRPORT	07/10/79	09/28/79	04/24/80	5R, 16
WINDSOR LOCKS	CT	BDL-BRADLEY INTERNATIONAL AIRPORT	06/22/79	09/27/79	04/22/80	15, 6
WORCESTER	MA	ORH-WORCESTER MUNICIPAL AIRPORT	06/22/79	10/11/79	04/22/80	15, 11
		NORTHWESTERN REGION				
BOISE	ID	BOI-BOISE AIR TERMINAL-GOWEN FLD	06/23/79	11/08/79	05/16/80	10L, 10R
EUGENE	OR	EUG-MAHLON SWEET FIELD	07/23/79	12/06/79	06/11/80	3, 16
IDAHO FALLS	ID	IDA-IDAHO FALLS MUNICIPAL AIRPORT	08/14/79	10/22/79	05/19/80	2
KLAMATH FALLS	OR	LMT-KINGSLEY FIELD	08/21/79	12/08/79		14
LEWISTON	ID	LWS-LEWISTON-NEZ PERCE CO. ARPT	06/26/79	11/10/79	05/18/80	8
MEDFORD	OR	MFR-MEDFORD-JACKSON CO. AIRPORT	08/22/79	12/10/79	06/12/80	14
PASCO	WA	PSC-TRI-CITIES AIRPORT	06/29/79	11/14/79	05/23/80	12, 3L
PENDLETON	OR	PDT-PENDLETON MUNICIPAL AIRPORT	06/30/79	11/14/79	05/22/80	7L
POCATELLO	ID	PIH-POCATELLO MUNICIPAL AIRPORT	10/23/79	05/17/80		3
PORTLAND	OR	PDX-PORTLAND INT'L AIRPORT	07/18/79	12/03/79	06/09/80	2, 10L, 10R
SALEM	OR	SLE-MCNARY FIELD	07/21/79	12/04/79	06/10/80	13
SEATTLE	WA	SEA-SEATTLE-TACOMA INT'L AIRPORT	07/05/79	11/18/79	06/06/80	16R, 16L
SPOKANE	WA	GEG-SPOKANE INTERNATIONAL AIRPORT	06/27/79	11/12/79		3, 7
TWIN FALLS	ID	TWF-TWIN FALLS CITY-COUNTY ARPT	06/22/79	11/07/79	05/15/80	7
YAKIMA	WA	YKM-YAKIMA AIR TERMINAL AIRPORT	07/03/79	11/15/79		9

CITY	ST	DES	AIRPORT NAME	TEST STARTING DATES			RWY(S)
			ROCKY MOUNTAIN REGION				
ABERDEEN	SD	ABR-ABERDEEN REGIONAL AIRPORT		06/15/79	10/22/79		13
BILLINGS	MT	BIL-BILLINGS LOGAN INT'L AIRPORT		07/13/79	10/12/79	06/10/80	9
BISMARK	ND	BIS-BISMARK MUNICIPAL AIRPORT		06/22/79	10/17/79	06/19/80	13
BOZEMAN	MT	BZM-GALLATIN FIELD AIRPORT		07/15/79	10/14/79	06/09/80	12
BUTTE	MT	BTM-MOONEY-SILVER BOW COUNTY ARPT		07/24/79	10/16/79	06/08/80	15
CASPER	WY	CPR-NATRONA CO INT'L AIRPORT		07/08/79	09/28/79	06/13/80	3, 16, 7, 12
CHEYENNE	WY	CYS-CHEYENNE MUNICIPAL AIRPORT		09/24/79			12, 8
COLORADO SPRINGS	CO	COS-CITY OF COLORADO SPRINGS MUNICIPAL AIRPORT		09/22/79	12/10/79	08/12/80	3, 17, 12
DENVER	CO	DEN-STAPLETON INT'L AIRPORT		09/25/79	12/06/79	08/14/80	8R, 8L, 17R, 17L
DURANGO	CO	DRO-DURANGO - LA PLATA CO AIRPORT		09/17/79	04/24/80		2
FARGO	ND	FAR-HECTOR FIELD		06/18/79	10/13/79	06/21/80	17
GRAND FORKS	ND	GFK-GRAND FORKS INT'L AIRPORT		06/19/79	10/15/79		17
GRAND JUNCTION	CO	GJT-WALKER FIELD		09/18/79	04/25/80	08/09/80	11
GREAT FALLS	MT	GTF-GREAT FALLS INT'L AIRPORT		07/18/79	10/17/79	05/22/80	16, 3
HELENA	MT	HLN-HELENA AIRPORT		07/17/79	10/16/79	05/24/80	8
JACKSON	WY	JAC-JACKSON HOLE AIRPORT		08/10/79	10/21/79		18
KALISPELL	MT	FCA-GLACIER PARK INT'L AIRPORT		07/20/79	10/18/79	05/21/80	1
MINOT	ND	MOT-MINOT INTERNATIONAL AIRPORT		06/20/79	10/16/79	06/19/80	13, 8
MISSOULA	MT	MSO-MISSOULA COUNTY AIRPORT		07/23/79	06/07/80		11
PIERRE	SD	PIR-PIERRE MUNICIPAL AIRPORT		06/24/79	10/22/79	06/18/80	7, 13
PUEBLO	CO	PUB-PUEBLO MEMORIAL AIRPORT		09/20/79	08/11/80		17, 8L
RAPID CITY	SD	RAP-RAPID CITY REGIONAL AIRPORT		06/26/79	10/19/79	06/17/80	14
RIVERTON	WY	RIW-RIVERTON REGIONAL AIRPORT		07/10/79	10/08/79	06/11/80	10
SALT LAKE CITY	UT	SLC-SALT LAKE CITY INT'L AIRPORT		08/16/79	11/04/79	05/15/80	16R, 16L
SHERIDAN	WY	SHR-SHERIDAN COUNTY AIRPORT		07/12/79	10/10/79		13, 5
SIOUX FALLS	SD	FSD-FOSS FIELD		06/13/79	11/03/79	08/25/80	15, 3
W YELLOWSTONE	MT	WYS-YELLOWSTONE AIRPORT		07/26/79	05/18/80		1
WATERTOWN	SD	ATY-WATERTOWN MUNICIPAL AIRPORT		06/14/79	10/23/79		12, 17

CITY	ST	DES	AIRPORT NAME	TEST STARTING DATES			RWY(S)
			SOUTHERN REGION				
AUGUSTA	GA	AGS-BUSH FIELD		12/20/79	02/18/80	04/16/80	17, 8
ALBANY	GA	ABY-ALBANY-DOUGHERTY CO AIRPORT		02/21/79	12/04/79	02/08/80	16, 4
ASHEVILLE	NC	AVL-ASHEVILLE REGIONAL AIRPORT		12/13/78 04/14/80	11/18/79	01/19/80	16
ATLANTA	GA	ATL-HARTSFIELD ATLANTA INT'L APT		12/06/78 06/12/80	11/16/79	01/16/80	9R, 9L, 8
BIRMINGHAM	AL	BHM-BIRMINGHAM MUNICIPAL AIRPORT		02/27/79	11/08/79	01/11/80	5
BRISTOL	NC	TRI-TRI-CITY AIRPORT		08/14/79	11/02/79	03/25/80	4
CHARLOTTE	NC	CLT-DOUGLAS MUNICIPAL AIRPORT		12/04/79	02/19/80	06/08/80	5, 18L, 18R
CHATTANOOGA	TN	CHA-LOVELL FIELD		12/09/78 04/09/80	08/11/79	11/05/79	14, 2
CINCINNATI	OH	CVG-GREATER CINCINNATI AIRPORT		11/10/78	03/19/80		9R, 9L, 18
COLUMBIA	SC	CAE-COLUMBIA METRO AIRPORT		01/03/79 04/17/80	12/19/79	02/16/80	11, 5
COLUMBUS	GA	CSG-COLUMBUS METROPOLITAN AIRPORT		02/25/79	11/12/79	01/12/80	5
COLUMBUS	MS	GTR-GOLDEN TRIANGLE REGIONAL ARPT		12/19/79	03/06/80	07/11/80	18
DAYTONA BEACH	FL	DAB-DAYTONA BEACH REGIONAL ARPT		10/24/79	01/08/80	06/16/80	6L
DOTHAN	AL	DHN-DOTHAN AIRPORT		12/05/79	02/10/80	06/21/80	13, 18
FAYETTEVILLE	NC	FAY-FAYETTEVILLE MUNI AIRPORT		12/14/79	02/14/80	04/21/80	3
FLORENCE	SC	FLO-FLORENCE CITY-COUNTY AIRPORT		12/18/78 04/18/80	12/18/79	02/15/80	18, 9
FORT MYERS	FL	FMY-PAGE FIELD		11/12/79	01/19/80		5
FT LAUDERDALE	FL	FLL-FORT LAUDERDALE-HOLLYWOOD INTERNATIONAL AIRPORT		02/01/79	11/07/79	01/16/80	9L, 13
GAINESVILLE	FL	GNV-GAINESVILLE REGIONAL AIRPORT		11/16/79	02/05/80		28
GREENSBORO	NC	GSO-GREENSBORO-HIGHPOINT-WINSTON SALEM REGIONAL AIRPORT		12/15/78	02/22/80	06/06/80	5, 14
GREENVILLE	MS	GLH-GREENVILLE INT'L AIRPORT		12/18/79	03/05/80	07/12/80	17R, 17L
GREER	SC	GSP-GREENVILLE-SPARTANBURG ARPT		11/19/79	01/19/80	04/15/80	3
GULFPORT	MS	GPT-GULFPORT-BILOXI REGIONAL ARPT		12/11/79	02/17/80	07/09/80	13, 17
HUNTSVILLE	AL	HSV-HUNTSVILLE-MADISON CO AIRPORT		11/30/78 04/10/80	11/06/79	01/10/80	18R, 18L
JACKSON	MS	JAN-ALLEN C THOMPSON FIELD ARPT (JACKSON REGIONAL AIRPORT)		03/01/79	12/15/79	02/20/80	15R, 15L
JACKSON	TN	MKL-MCKELLAR FIELD AIRPORT		07/17/79	10/17/79	03/11/80	2

CITY	ST	DES	AIRPORT NAME	TEST STARTING DATES			RWY(S)
JACKSONVILLE	FL	JAX-JACKSONVILLE INT'L AIRPORT	02/16/79 06/14/80	10/23/79	01/05/80	13, 7
JACKSONVILLE	NC	OAJ-ALBERT J ELLIS AIRPORT	12/13/79	02/12/80	04/23/80	5
KINSTON	NC	ISO-EASTERN REGIONAL JETPORT	12/12/79	02/11/80	04/24/80	4, 18
KNOXVILLE	TN	TYS-MCGHEE TYSON AIRPORT	12/12/78 03/25/80	08/13/79	11/03/79	4L, 4R
LAUREL-HATTIESBURG	MS	PIB-PINE BELT REGIONAL AIRPORT	12/14/79	02/18/80	07/10/80	18
LEXINGTON	KY	LEX-BLUE GRASS FIELD	11/13/78	07/23/79	03/21/80	4
LOUISVILLE	KY	SDF-STANDIFORD FIELD AIRPORT	11/18/78 07/18/80	08/10/79	10/24/79	6, 1, 11
MACON	GA	MCN-LEWIS B WILSON AIRPORT	02/24/79	11/13/79	01/13/80	5, 13
MELBOURNE	FL	MLB-MELBOURNE REGIONAL AIRPORT	11/05/79	01/10/80	06/17/80	9
MEMPHIS	TN	MEM-MEMPHIS INT'L AIRPORT	11/20/78 07/15/80	07/14/79	10/13/79	3, 9, 17R, 17L
MERIDIAN	MS	MEI-MERIDIAN MUNICIPAL AIRPORT	12/14/79	02/19/80	07/10/80	1
MIAMI	FL	MIA-MIAMI INTERNATIONAL AIRPORT	01/30/79	11/09/79	01/18/80	9R, 9L, 12
MOBILE	AL	MOB-MOBILE MUNICIPAL AIRPORT	12/10/79	02/14/80	07/08/80	14
MONTGOMERY	AL	MGM-DANNELLY FIELD AIRPORT	02/26/79	11/09/79	01/12/80	9
MUSCLE SHOALS	AL	MSL-MUSCLE SHOALS AIRPORT	01/06/80	03/08/80	07/17/80	11
NASHVILLE	TN	BNA-NASHVILLE METROPOLITAN ARPT	11/19/78 03/10/80	07/18/79	10/19/79	13, 2L
ORLANDO	FL	MCO-ORLANDO INTERNATIONAL AIRPORT	02/13/79	11/03/79	01/09/80	18R, 18I
PADUCAH	KY	PAH-BARKLEY REGIONAL AIRPORT	07/12/79	11/11/79	03/13/80	4
PANAMA CITY	FL	PFN-PANAMA CITY-BAY COUNTY ARPT	12/07/79	02/12/80	06/23/80	14
PENSACOLA	FL	PNS-PENSACOLA REGIONAL AIRPORT	12/08/79	02/13/80	06/24/80	7, 16
RALEIGH-DURHAM	NC	RDU-RALEIGH-DURHAM AIRPORT	12/17/78	12/11/79	03/07/80	5
SARASOTA	FL	SRQ-SARASOTA-BRADENTON AIRPORT	11/13/79	02/01/80	06/18/80	13, 4
SAVANNAH	GA	SAV-SAVANNAH MUNICIPAL AIRPORT	01/09/79	10/22/79	01/03/80	9, 18
TALLAHASSEE	FL	TLH-TALLAHASSEE MUNICIPAL AIRPORT	02/20/79	11/19/79	02/07/80	18
TAMPA	FL	TPA-TAMPA INTERNATIONAL AIRPORT	02/09/79	11/15/79	02/03/80	9, 18R, 18L
TUSCALOOSA	AL	TCL-TUSCALOOSA MUNICIPAL AIRPORT	01/05/80	03/07/80		4
VALDOSTA	GA	VLD-VALDOSTA MUNICIPAL AIRPORT	11/17/79	02/06/80	06/13/80	3, 17
WEST PALM BCH	FL	PBI-PALM BEACH INT'L AIRPORT	02/06/79	11/06/79	01/12/80	13, 9L
WILLMINGTON	NC	ILM-NEW HANOVER COUNTY AIRPORT	12/17/79	02/13/80	04/22/80	5, 16
WINSTON-SALEM	NC	INT-SMITH REYNOLDS AIRPORT	12/07/79	02/21/80	06/07/80	15

CITY	ST	DES	AIRPORT NAME	[illegible]	[illegible]	[illegible]	RWY(S)
			SOUTHWESTERN REGION				
ABILENE	TX	ABI-ABILENE MUNICIPAL AIRPORT		01/[illegible]/80	03/17/[illegible]	07/24/80	17L, [illegible]
ALBUQUERQUE	NM	ABQ-ALBUQUERQUE SUNPORT INT'L APT		12/14/79	03/05/[illegible]	08/11/80	8, 17
AUSTIN	TX	AUS-ROBERT MUELLER MUNI AIRPORT		01/08/80	03/12/80	07/15/80	16R, 12R
ALEXANDRIA	LA	ESF-ESLER REGIONAL AIRPORT		11/20/79	01/21/80	06/06/80	8, 14
BATON ROUGE	LA	BTR-RYAN AIRPORT		12/04/79	02/05/80		4, 13
BEAUMONT	TX	BPT-JEFFERSON COUNTY AIRPORT		12/16/79	02/12/80	06/14/80	16, 12
BROWNSVILLE	TX	BRO-BROWNSVILLE INT'L AIRPORT		12/19/79	[illegible]	06/23/80	13R, 17L, 17R
CORPUS CHRISTI	TX	CRP-CORPUS CHRISTI INT'L AIRPORT		12/18/79	[illegible]	06/2[illegible]/80	13, 17
DALLAS	TX	DAL-DALLAS LOVE FIELD		01/12/80	03/15/80	07/23/80	13L, 13R
DALLAS-FT WRTH	TX	DFW-DALLAS-FT WORTH REGIONAL ARPT		01/10/80	03/14/80	07/18/80	17L, 17R, 13L
EL PASO	TX	ELP-EL PASO INTERNATIONAL AIRPORT		12/18/79	02/18/80	08/06/80	4, 8
FORT SMITH	AR	FSM-FORT SMITH MUNICIPAL AIRPORT		11/14/79	01/14/80	05/19/80	7
HARLINGEN	TX	HRL-HARLINGEN INDUS AIRPARK ARPT		01/04/80	03/0[illegible]/80	06/26/80	17R, 17L
HOUSTON	TX	IAH-HOUSTON INTERCONTINENTAL ARPT		12/15/79	02/16/80	06/16/80	14, 8
HOUSTON	TX	HOU-WILLIAM P. HOBBY AIRPORT		12/15/79	02/14/80	06/14/80	4, [illegible]
LAFAYETTE	LA	LFT-LAFAYETTE REGIONAL AIRPORT		12/07/79	02/08/80	06/09/80	3, [illegible], 1
LAKE CHARLES	LA	LCH-LAKE CHARLES MUNI AIRPORT		12/10/79	02/11/80	06/10/80	15
LAREDO	TX	LRD-LAREDO INTERNATIONAL AIRPORT		01/05/80	03/0[illegible]/80	0[illegible]/12/80	17C, 14
LAWTON	OK	LAW-LAWTON MUNICIPAL AIRPORT		01/08/80	03/08/80	08/1[illegible]/80	17
LITTLE ROCK	AR	LIT-LITTLE ROCK REGIONAL AIRPORT		11/13/79	01/16/80	05/23/80	4
LUBBOCK	TX	LBB-LUBBOCK INTERNATIONAL AIRPORT		12/20/79	03/05/80	08/13/80	8, 17R
MCALLEN	TX	MFE-MILLER INTERNATIONAL AIRPORT		01/03/80	03/05/80	07/10/80	13
MIDLAND	TX	MAF-MIDLAND REGIONAL AIRPORT		01/18/80	03/19/80	07/25/80	16R, 10
MONROE	LA	MLU-MONROE REGIONAL AIRPORT		11/19/79	01/19/80	05/25/80	13, 4
NEW ORLEANS	LA	MSY-NEW ORLEANS INTERNATIONAL APT		12/05/79	02/07/80	06/08/80	10, 1
OKLAHOMA CITY	OK	OKC-WILL ROGERS WORLD AIRPORT		01/10/80	03/10/80	08/18/80	17L, 17R, 12
ROSWELL	NM	ROW-ROSWELL INDUSTRIAL AIR CENTER		12/17/79	02/20/80	08/10/80	3, 17
SAN ANGELO	TX	SJT-MATHIS FIELD AIRPORT		01/17/80	03/19/80	07/25/80	18, 3
SAN ANTONIO	TX	SAT-SAN ANTONIO INT'L AIRPORT		03/10/80	07/14/80		3R, 12R
SHREVEPORT	LA	SHV-SHREVEPORT REGIONAL AIRPORT		11/17/79	01/18/80	05/24/80	13
TEXARKANA	AR	TXK-TEXARKANA MUNI-WEBB FIELD APT		11/16/79	01/17/80		4, 13
TULSA	OK	TUL-TULSA INTERNATIONAL AIRPORT		01/15/80	05/20/80	08/20/80	17R, 17L, 8
WITCHITA FALLS	TX	SPS-SHEPPARD AIR FORCE BASE		01/05/80	03/07/80	08/14/80	15R, 15L

CITY	ST	DES	AIRPORT NAME	TEST STARTING DATES			RWY(S)
			WESTERN REGION				
ARCATA	CA	ACV-ARCATA-EUREKA AIRPORT		08/24/79	12/11/79	06/13/80	13
BAKERSFIELD	CA	BFL-BAKERSFIELD MEADOWS FIELD		02/01/80	04/09/80	07/11/80	12L
BURBANK	CA	BUR-BURBANK-GLENDALE-PASADENA APT		02/04/80	04/10/80	07/12/80	7, 15
ELKO	NV	EKO-ELKO MUNICIPAL AIRPORT		08/20/79	11/06/79	05/14/80	5
ELY	NV	ELY-YELLAND FIELD		08/17/79	11/05/79	03/26/80	18
FRESNO	CA	FAT-FRESNO AIR TERMINAL		02/02/80	03/22/80	07/10/80	11L
GRAND CANYON	AZ	GCN-GRAND CANYON NATIONAL PRK APT		09/15/79	03/23/80	08/07/80	3
LAS VEGAS	NV	LAS-MCCARRAN INT'L AIRPORT		09/14/79			1R, 7
LONG BEACH	CA	LGB-LONG BEACH MUNICIPAL AIRPORT		01/18/80	04/08/80	07/18/80	12, 7R
LOS ANGELES	CA	LAX-LOS ANGELES INT'L AIRPORT		01/15/80	03/24/80	07/15/80	6L, 6R, 7L, 7R
MODESTO	LA	MOD-MODESTO CITY-COUNTY AIRPORT		01/14/80	03/18/80	07/09/80	10L
MONTEREY	CA	MRY-MONTEREY PENINSULA AIRPORT		01/05/80	03/19/80	07/08/80	10
OAKLAND	CA	OAK-METRO-OAKLAND INT'L AIRPORT		12/15/79	03/10/80	06/18/80	9R, 9L, 11
ONTARIO	CA	ONT-ONTARIO INTERNATIONAL AIRPORT		02/06/80	04/14/80	07/21/80	7L
PALM SPRINGS	CA	PSP-PALM SPRINGS MUNI AIRPORT		02/05/80	04/15/80	07/22/80	12
PHOENIX	AZ	PHX-PHOENIX SKY HARBOR INT'L ARPT		02/13/80	04/22/80	08/06/80	8R, 8L
REDDING	CA	RDD-REDDING MUNICIPAL AIRPORT		08/25/79	12/12/79	06/15/80	16, 12
RENO	NV	RNO-RENO INTERNATIONAL AIRPORT		09/11/79	06/17/80		16, 7
SACRAMENTO	CA	SMF-SACRAMENTO METRO AIRPORT		12/13/79	03/09/80		16
SAN DIEGO	CA	SAN-SAN DIEGO INT'L AIRPORT		02/10/80	04/17/80		9
SAN FRANCISCO	CA	SFO-SAN FRANCISCO INT'L AIRPORT		01/09/80	03/13/80	06/22/80	1R, 1L, 19R, 19L
SAN JOSE	CA	SJC-SAN JOSE MUNICIPAL AIRPORT		01/07/80	03/17/80	07/07/80	12R
SANTA ANA	CA	SNA-JOHN WAYNE AIRPORT		02/07/80	04/12/80	07/19/80	01L
SANTA BARBARA	CA	SBA-SANTA BARBARA MUNI AIRPORT		02/08/80	04/11/80	07/14/80	007
STOCKTON	CA	SCK-STOCKTON METROPOLITAN AIRPORT		01/14/80	03/18/80	07/08/80	11L
TUCSON	AZ	TUS-TUCSON INTERNATIONAL AIRPORT		02/15/80	04/18/80	07/25/80	[illegible], 11[illegible]

APPENDIX B

GLOSSARY

Asphalt, slurry seal - A pavement with a thin layer of asphalt and aggregate applied over an existing asphalt pavement.

Asphalt, new - A pavement which is typically dark in appearance where the aggregate is covered by asphalt.

Asphalt, microtexture - A pavement which displays a gritty texture and the sand matrix is intact at the surface.

Asphalt, mixed texture - A pavement in which the asphalt is worn away from the surface exposing the sand matrix and the coarse aggregate.

Asphalt, macrotexture - A pavement in which the predominant surface is coarse aggregate and the sand matrix is worn away.

Asphalt, worn - A pavement which has protruding coarse aggregate and the asphalt and the sand matrix are worn away.

Asphalt, porous friction course - A pavement with an open graded surface of coarse aggregate.

Asphalt, chip seal - A pavement with aggregate chips applied onto an asphalt seal.

Asphalt, rubberized chip seal - A pavement in which a chip seal is held to the subsurface by a rubberized material.

Cleaned Runway - A runway approach end from which rubber has been removed.

Concrete, microtexture - A pavement in which the surface is predominantly a sand matrix.

Concrete, macrotexture - A pavement in which the surface is predominantly coarse aggregate, typically due to wearing away of the sand matrix.

Concrete, burlap dragged - A pavement which displays a surface characteristic resulting from the dragging of burlap or similar material on concrete surface while still plastic.

Concrete, broomed or brushed - A pavement which displays a surface characteristic of finely spaced markings resulting from brushing the concrete while still plastic.

Concrete, wire combed - A pavement which displays a surface characteristic of transverse indentations spaced 1/4-inch or less, resulting from rigid combing of the concrete while still plastic.

Concrete, wire-tined - A pavement which displays a surface characteristic of transverse indentations spaced one-fourth inch or more resulting from flexible raking of the concrete while still plastic.

Concrete, float grooved - A pavement which has regularly spaced transverse grooves formed in the concrete while still plastic.

Concrete, worn - A pavement which has protruding coarse aggregate and the surface may have begun to abraid.

Contaminant - Any foreign substance present on the pavement surface.

Correlation Coefficient - A statistic which summarizes the relationship between two variables, a value of +1 or -1 indicates a perfect linear relationship, while a value near 0 indicates a poor relationship.

Groove Deterioration - The degree of ineffectiveness of the groove for channeling water rated on an integer scale of 0 to 9, 0 representing full effectiveness and 9 indicating total ineffectiveness due to being filled, missing or poorly constructed.

Groove Spacing - The center to center distance between two grooves.

Joint Distress - The degree to which the joints between slabs are open, rated on an integer scale from 0 to 9, 0 representing no joint distress, 9 indicates joints are open more than one inch, with pieces of pavement broken away.

Multiple Regression - A statistical technique used to analyze the relationship between a dependent variable and one or more predictor variables.

Mu Value - The value recorded on the Mu-Meter chart representing the friction force developed by operating the Mu-Meter at 40 mph with 0.04 inches of water applied immediately in front of the measuring tires.

Rubber Accumulation - The degree of rubber accumulation on the pavement surface rated on an integer scale from 0 to 9, 0 representing less than 10 percent of the pavement surface obliterated, 9 representing 90 percent or more of the surface texture obliterated.

Saw-Cut Grooves - Transverse grooves cut into a cured asphalt or concrete surface.

Standard Error - A statistic which identifies the standard deviation of a typical measurement from the mean value of a group of measurements.

Structural Distress - The degree of cracking or breakup of the pavement surface rated on an integer scale from 0 to 9, 0 representing no structural deterioration, 9 representing alligator pieces chucking out for asphalt pavements and block cracking or spalling for concrete pavements.

For more detailed definitions and examples, refer to "Phase [illegible] Operator's Manual for the National Runway Friction Measurement [illegible], H.A. Hickok and Associates, April 1979.

APPENDIX C

Sample Airport Survey Report

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APPENDIX C - SAMPLE AIRPORT REPORT

AIRPORT SURVEY REPORT

AIRPORT NAME (DES)

CITY, ST

1. INTRODUCTION

Friction measurements were made at the Airport Name Airport on January 11-12, 1980 as part of the National Runway Friction Measurement Program. This survey report describes the program and the results of the measurements taken on Runways 11-20 and 8-26.

2. AIRPORT SURVEY COORDINATION

An airport contact meeting was held on January 11, 1980, with the following persons in attendance:

Mr. James A. Smith, Airport Manager
Ms. Mary McBride, E.A. Hickok and Associates
Mr. Brian Pluemer, E.A. Hickok and Associates

3. SURVEY PROCEDURES

The friction measurements were performed with a Mu-Meter towed at 40 miles per hour 10 feet to the right of the runway centerline in both directions, under both dry and wet conditions. The Mu-Meter evaluates the side-force friction between the tires and pavement surface, and it contains a self watering system.

A pavement condition survey was performed to evaluate such factors as pavement type, pavement texture, presence and condition of grooving, marking type and condition, rubber accumulation, contaminant accumulation, joint condition and structural conditions. These characteristics will be evaluated with the friction measurements. Visual observations of the pavement surface condition were made during a low speed pass over the runway and at stopping points as required to make local visual inspections. Spot tests were performed at four locations on each runway, and included texture measurement (NASA grease smear test), transverse slope measurements and stereo photographs of the texture.

DISCUSSION

The friction measurements and related data for the runways are presented in Tables DES-1 and DES-2. The last portion of the table summarizes the pavement condition survey.

The friction data were evaluated based on measurement parameters given in paragraph 4 of Chapter 2, AC 150/5320-12, Methods for the Design, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces. The recommended average wet Mu value for a 500-foot increment of runway length is greater than or equal to 50, according to AC 150/5320-12. Mu values, as reported here, are multiplied by 100 and thus range from 0 to 100.

Runway 11-29 was surveyed on January 11, 1980 (see Table DES-1). The average wet Mu value was equal to or greater than 50 for all 500-foot increments of runway length.

Runway 8-26 was surveyed on January 11-12, 1980 (see Table DES-2). The average wet Mu value was less than 50 between 1500-2000 feet from the Runway 8 threshold. Significant rubber accumulation was observed in this same area.

Measurements at the Airport Name Airport during January 1980 indicate that the average wet Mu value was less than 50 for portions of Runway 8-26 and equal to or greater than 50 for all 500-foot increments of Runway 11-29.

It should be noted that some of the wet Mu values approximate the dry Mu values in areas where good friction characteristics are encountered.

V. SUMMARY

The results of the January 1980 friction survey at Airport Name Airport indicate that Runway 8-26 has a 500-foot section below the recommended friction value and Runway 11-29 meets the recommended friction values based on present criteria.

The results of previous friction surveys conducted in June 1979 and October 1979 indicated the two runways met recommended friction values.

The January 1980 survey completes the scheduled National Runway Friction Measurement Program testing at Airport Name Airport. A final report for the program will be presented to the Federal Aviation Administration in late 1980 and will be available to interested parties in early 1981. The excellent cooperation of the airport staff through the program has been greatly appreciated.

NATIONAL RUNWAY FRICTION MEASUREMENT PROGRAM

TABLE DES - 1 AIRPORT NAME

SITE NUMBER: 1111

SURVEY RESULTS FOR RUNWAY 11-29

DATE: 1/11/80 LEADER: BRP
TIME: 1240 - 1500 ASSISTANT: MFM
RUNWAY LENGTH: 5500 FEET

PAVEMENT SURFACE: (11) ASPHALT, 0- 560, WORN SURFACE
CONCRETE, 560- 640, BURLAP DRAGGED
ASPHALT, 640-4010, WORN SURFACE
ASPHALT, 4010-4650, MIXED-TEXTURE
ASPHALT, 4650-5500, WORN SURFACE

GROOVING TYPE: (11) 0- 500, NONE
500- 680, SAW-CUT GROOVES
680-5500, NONE

FRICTION (MU) VALUES

RUNWAY 11 SEGMENT (FT)	DRY MU	WET MU	RUNWAY 29 SEGMENT (FT)	DRY MU	WET MU
* 0 - 500	80	75	* 5500 - 5000	81	84
500 - 1000	82	74	5000 - 4500	80	78
1000 - 1500	82	81	4500 - 4000	83	82
1500 - 2000	83	81	4000 - 3500	84	86
2000 - 2500	82	83	3500 - 3000	84	[illegible]
2500 - 3000	83	82	3000 - 2500	83	78
3000 - 3500	83	74	2500 - 2000	83	76
3500 - 4000	81	77	2000 - 1500	81	[illegible]
4000 - 4500	81	65	1500 - 1000	79	[illegible]
4500 - 5000	81	72	1000 - 500	83	68
* 5000 - 5500	83	80	* 500 - 0	79	79
AVERAGE	82	77	AVERAGE	82	77

NOTE: Mu measured 10 ft right of centerline.
*These segments were not measured at 40 mph and are not included in average.

TEMPERATURE DATA

AIR TEMPERATURE (C)	20
PAVEMENT TEMPERATURE (C)	29
WATER TEMPERATURE (C)	15

TABLE DES - 1 CONTINUED

RELATED MEASUREMENTS: RUNWAY 11

STATION (FT)	OFFSET (FT)	TRANSVERSE SLOPE (%)	NASA GREASE SMEAR TEXTURE (IN)	GROOVING SPACING (MM)	GROOVING WIDTH (MM)	GROOVING DEPTH (MM)	RUBBER RATING
1160	10	0.7	0.025	-	-	-	0
2710	10	0.8	0.042	-	-	-	0
2710	70	-0.5	0.042	-	-	-	0
4010	10	1.1	0.021	-	-	-	0

PAVEMENT CONDITION SURVEY RESULTS

RUNWAY 11

(Conditions are rated on a scale of 0 to 9, 0 representing the best condition)

	SEGMENT (FT)	TYPE	RATING
RUBBER ACCUMULATION	0 - 680		0
	680 - 720		2
	720 - 5500		0
STRUCTURAL DISTRESS	0 - 230		0
	230 - 320		3
	820 - 960		6
	960 - 2740		3
	2740 - 2800		1
	2800 - 5500		3
JOINT DISTRESS	0 - 230		0
	230 - 2740		3
	2740 - 2800		1
	2800 - 5500		3
GROOVING CONDITION	500 - 680	SAW CUT	1
CONTAMINANT CONDITION	0 - 5500	NONE	0

NATIONAL RUNWAY FRICTION MEASUREMENT PROGRAM

TABLE DES - 2 AIRPORT NAME

SITE NUMBER: 1111[illegible]

SURVEY RESULTS FOR RUNWAY 8-26

DATE: 1/11-12/80 LEADER: BRP
TIME: 2045 - 2110 ASSISTANT: MFM
RUNWAY LENGTH: 8000 FEET
PAVEMENT SURFACE: (8) CONCRETE, 0-1000, BROOMED
CONCRETE, 1000-1800, MICROTEXTURE
CONCRETE, 1800-8000, BURLAP DRAGGED
GROOVING TYPE: (8) 0-8000, SAW-CUT GROOVES

FRICTION (MU) VALUES

RUNWAY 8			RUNWAY 26		
SEGMENT (FT)	DRY MU	WET MU	SEGMENT (FT)	DRY MU	WET MU
* 0 - 500	79	74	* 8000 - 7500	82	76
500 - 1000	82	69	7500 - 7000	80	7[illegible]
1000 - 1500	78	58	7000 - 6500	75	57
1500 - 2000	76	48	6500 - 6000	76	56
2000 - 2500	79	61	6000 - 5500	81	7[illegible]
2500 - 3000	82	70	5500 - 5000	83	7[illegible]
3000 - 3500	83	70	5000 - 4500	82	74
3500 - 4000	82	67	4500 - 4000	82	7[illegible]
4000 - 4500	82	75	4000 - 3500	8[illegible]	7[illegible]
4500 - 5000	82	77	3500 - 3000	8[illegible]	75
5000 - 5500	80	71	3000 - 2500	81	7[illegible]
5500 - 6000	80	68	2500 - 2000	81	6[illegible]
6000 - 6500	80	63	2000 - 1500	76	5[illegible]
6500 - 7000	76	62	1500 - 1000	76	6[illegible]
7000 - 7500	79	62	1000 - 500	77	56
* 7500 - 8000	82	75	* 500 - 0	77	70
AVERAGE	80	66	AVERAGE	80	67

NOTE: Mu measured 10 ft right of centerline.
*These segments were not measured at 40 mph and are not included in average.

TEMPERATURE DATA

AIR TEMPERATURE (C)	20
PAVEMENT TEMPERATURE (C)	27
WATER TEMPERATURE (C)	15

TABLE DES - 2 CONTINUED

RELATED MEASUREMENTS: RUNWAY 8

STATION (FT)	OFFSET (FT)	TRANSVERSE SLOPE (%)	NASA GREASE SMEAR TEXTURE (IN)	GROOVING SPACING (MM)	GROOVING WIDTH (MM)	GROOVING DEPTH (MM)	RUBBER RATING
2000	10	0.8	0.004	37	7	6	1
4000	10	1.2	0.008	38	7	5	0
4000	70	-0.6	0.018	38		7	0
6000	10	1.1	0.003	38	7	6	2

TABLE DES - 2 CONTINUED

PAVEMENT CONDITION SURVEY RESULTS

RUNWAY 8

(Conditions are rated on a scale of 0 to 9, 0 representing the best condition)

	SEGMENT (FT)	TYPE	RATING
RUBBER ACCUMULATION	0 - 1040		0
	1040 - 1160		1
	1160 - 1300		3
	1300 - 1760		2
	1760 - 2100		1
	2100 - 5600		0
	5600 - 5940		1
	5940 - 6180		2
	6180 - 6360		3
	6360 - 6600		4
	6600 - 7130		2
	7130 - 7300		1
	7300 - 8000		0
STRUCTURAL DISTRESS	0 - 1800		3
	1800 - 7550		1
	7550 - 8000		3
JOINT DISTRESS	0 - 950		1
	950 - 1800		5
	1800 - 7550		1
	7550 - 8000		5
GROOVING CONDITION	0 - 8000	SAW CUT	1
CONTAMINANT CONDITION	0 - 8000	NONE	0

APPENDIX D

Uniform Segments Data Characteristics

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TABLE D-1

SUMMARY OF MU VALUES FOR UNIFORM SEGMENTS

Pavement Type	Number of Runways	Number of Uniform Segments	Range	Mean	Standard Deviation	<40	40–45	46–50	51–55	56–60	61–70	71–80	>80
			Wet Mu Value										
ASPHALT:													
New	8	722	32–88	61.0	13.6	47	60	61	88	71	192	162	41
Microtexture	39	2061	26–88	64.2	9.8	18	48	95	241	370	701	512	76
Mixed Texture	71	4445	9–92	65.8	11.3	117	113	176	289	460	1713	1340	237
Macrotexture	30	1523	31–88	72.7	9.0	7	14	18	40	73	345	744	282
Worn	29	1213	31–89	73.2	8.3	2	4	16	27	31	321	570	242
Porous Friction Course	51	2939	44–89	77.0	5.9	0	1	2	11	38	315	1438	1134
Chip Seal	13	567	52–89	74.5	7.4	0	0	0	5	16	140	231	165
Rubberized Chip Seal	7	329	34–87	68.8	12.6	8	13	13	13	30	90	91	71
Slurry Seal	10	286	41–85	69.7	7.6	0	2	3	9	25	97	126	24
ASPHALT WITH SAW CUT GROOVES:													
New	4	255	41–83	72.2	6.3	0	3	2	1	1	76	163	9
Microtexture	35	1991	44–88	73.2	7.5	0	3	13	22	77	535	1012	329
Mixed Texture	69	3636	35–89	71.5	7.9	6	23	32	80	186	1115	1801	393
Macrotexture	14	649	49–86	72.3	7.2	0	0	3	13	32	174	356	71
Worn	3	121	48–90	69.6	8.5	0	0	3	2	9	58	35	14
CONCRETE:													
Microtexture	7	352	25–76	57.5	8.8	7	16	65	51	76	100	37	0
Macrotexture	0	43	60–72	66.1	3.1	0	0	0	0	1	40	2	0
Worn	4	177	35–86	64.1	8.7	1	2	2	17	44	77	26	8
Burlap Dragged	23	1500	11–77	71.0	4.9	41	70	173	340	403	423	50	0
Broomed or Brushed	11	764	27–83	60.1	11.5	30	67	59	108	114	223	157	6
Wire Combed	7	500	27–87	68.4	11.5	10	22	29	40	30	144	189	36
Wire Tined	10	755	38–81	68.2	8.4	2	7	17	49	73	255	324	28
Float Grooved	7	479	33–79	64.1	7.8	4	12	13	35	64	253	98	0
CONCRETE WITH SAW CUT GROOVES:													
Microtexture	9	688	27–81	69.5	8.9	2	4	18	38	70	133	407	16
Macrotexture	1	54	54–80	69.0	6.3	0	0	0	1	4	23	26	0
Worn	4	226	46–80	71.0	4.9	0	0	2	1	5	68	150	0
Burlap Dragged	19	1992	34–87	71.8	7.9	3	12	36	49	91	488	1167	146
Broomed or Brushed	4	442	40–84	67.8	7.0	0	2	5	15	35	213	167	5
Wire Tined	2	140	53–80	72.6	5.1	0	0	0	3	1	30	106	0
TOTAL	491	28,849				305	498	856	1,588	2,430	8,342	11,487	3,327

TABLE D-2

SUMMARY OF GROOVE DIMENSION FOR UNIFORM SEGMENTS

Pavement	Number of Grooved Segments	1.25 Inches or Less	1.5 Inches	1.75 Inches	2.0 Inches	2.25 Inches	2.50 Inches	3.0 Inches
ASPHALT								
New	255	77	114	34	30	0	0	0
Microtexture	1991	741	590	138	280	202	40	0
Mixed Texture	3636	1721	937	290	546	122	20	0
Macrotexture	649	291	336	0	22	0	0	0
Worn	121	22	99	0	0	0	0	0
CONCRETE								
Microtexture	688	533	8	0	147	0	0	0
Macrotexture	54	37	4	0	13	0	0	0
Worn	226	186	40	0	0	0	0	0
Burlap Dragged	1992	711	455	0	826	0	0	0
Broomed or Brushed	442	184	191	0	40	0	0	27
Wire Tined	140	0	68	0	72	0	0	0
TOTAL	10,194	4,503	2,842	462	1,976	324	60	27

TABLE [illegible]

SUMMARY OF RUBBER RATING FOR UNIFORM SEGMENTS

	Number of Uniform Segments	Mean	Standard Deviation	Rubber Rating Breakdown 0	1	2	3	4	5	6	7	8	9
ASPHALT:													
New	722	0.1	0.5	665	34	13	5	5					
Microtexture	2061	0.4	[illegible]	1695	187	62	50	22	21	9	11	4	
Mixed Texture	4467	0.4	1.3	3721	324	130	109	52	38	29	38	18	8
Macrotexture	1523	0.2	[illegible]	1332	113	40	16	12	8	2			
Worn	1213	0.2	0.7	1103	63	16	19	6	3	3			
Porous Friction Course	2939	0.1	[illegible]	2701	159	41	20	10	4	1	2	1	
Chip Seal	567	0.1	0.3	528	30	9							
Rubberized Chip Seal	329	0.7	1.5	242	31	13	17	11	9	4	2		
Slurry Seal	286	0.2	0.8	268	4	[illegible]	6	4	2				
ASPHALT WITH SAW-CUT GROOVES:													
New	255	0.4	1.0	212	14	16	5	6	2				
Microtexture	1991	0.6	1.3	1518	190	101	73	43	28	29	5	4	
Mixed Texture	3636	0.7	[illegible]	2652	373	209	161	97	83	34	21	6	
Macrotexture	[illegible]	0.6	[illegible]	493	59	43	28	11	8	3	3	1	
Worn	121	0.5	1.3	100	6	5	6	0	2	1	1		
CONCRETE:													
Microtexture	352	0.3	0.8	295	31	15	5	4		2			
Macrotexture	43	0.02	0.2	42	1								
Worn	177	0.06	0.2	167	10								
Burlap Dragged	1391	0.5	1.3	1170	168	70	33	18	17	7	10	6	2
Broomed or Brushed	764	0.7	[illegible]	539	103	45	25	12	12	14	14		
Wire Combed	500	0.7	[illegible]	[illegible]	86	36	18	13	7	3			
Wire Tined	755	0.5	[illegible]	598	60	40	30	10	5	6	4	2	
Float Grooved	479	0.5	[illegible]	[illegible]	15	13	5	11	5	12	2		
CONCRETE WITH SAW-CUT GROOVES:													
Microtexture	[illegible]	0.4	[illegible]	551	59	33	37	5	[illegible]	2			
Macrotexture	54	0.3	[illegible]	44	4	6							
Worn	226	0.7	[illegible]	162	24	20	6	4	4	4	2		
Burlap Dragged	[illegible]	[illegible]	[illegible]	[illegible]	198	[illegible]	[illegible]	51	32	23	8	12	
Broomed or Brushed	412	0.7	[illegible]	[illegible]	46	42	[illegible]	30	6	6	1		
[illegible]	140	0.4		[illegible]	19	14	[illegible]						
Total	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	298	194	12[illegible]	51	10

[illegible]

SUMMARY OF JOINT RATING FOR UNIFORM SEGMENTS

	Number of Uniform Segments	Mean	Standard Deviation	Joint Rating Breakdown [illegible]	[illegible]	[illegible]	3	4	5	6	7	8	[illegible]
[illegible]													
[illegible]	7[illegible]	[illegible]		6	[illegible]	[illegible]	2[illegible]						
Mi[illegible]	2061	[illegible]	1.[illegible]	[illegible]	343	[illegible]	[illegible]	1[illegible]0	48		[illegible]		
Mixe[illegible]	14[illegible]	[illegible]	1.3	13[illegible]	28[illegible]	[illegible]	[illegible]	277	123	34	16	2	2
M[illegible]rotexture	15[illegible]	[illegible]	1.[illegible]	2[illegible]	1[illegible]	234	[illegible]	2[illegible]9	42	1	1		
Worn	12[illegible]	[illegible]	1.[illegible]	1[illegible]	16[illegible]	350	122	243	92	6	7		
P[illegible] Friction Course	29[illegible]	[illegible]	1.[illegible]	15[illegible]	[illegible]	[illegible]	[illegible]	268	87	11	2	10	
Chip Seal	56[illegible]	[illegible]	1.3	1[illegible]5	7[illegible]	167	[illegible]36	24	3				
Rubberized Chip Seal	32[illegible]	[illegible]	1.3	209	3[illegible]	[illegible]	26	18	2				
Slurry Seal	28[illegible]	2.4	1.4	[illegible]	56	54	99	22	14	6			
[illegible]													
New	2	[illegible]	[illegible]	[illegible]	1[illegible]	2	2[illegible]	18					
Micr[illegible]texture	[illegible]	[illegible]	1.5	12[illegible]	[illegible]		[illegible]	82	39	1[illegible]			
M[illegible] Texture	36[illegible]	[illegible]	1.5	15[illegible]	[illegible]	[illegible]	[illegible]	169	76	[illegible]	[illegible]	16	[illegible]
Macrotexture	6[illegible]	[illegible]	1.[illegible]	225	1[illegible]		3[illegible]	63	15				
Wo[illegible]	12[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	5	1				
[illegible]													
M[illegible]otexture	3[illegible]	[illegible]	1.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	2	
Macrotexture		1.2	[illegible]	[illegible]	[illegible]	12							
Worn	1	1[illegible]	1.1	[illegible]		[illegible]	2[illegible]	[illegible]					
B[illegible]	150[illegible]	[illegible]	1.5	[illegible]	[illegible]	[illegible]	[illegible]	38	[illegible]	[illegible]	1[illegible]	1	
B[illegible]	[illegible]	[illegible]	1.2	3[illegible]	[illegible]	[illegible]1	[illegible]	[illegible]	[illegible]	1	2		
W[illegible]	50[illegible]	[illegible]	0.7	2[illegible]	[illegible]	86							
W[illegible]	7	[illegible]	0.8	[illegible]	14[illegible]	[illegible]	1[illegible]	[illegible]					
[illegible]	4	[illegible]	[illegible]		[illegible]	26							
[illegible]													
M[illegible]otexture	[illegible]	[illegible]	[illegible]	[illegible]	223	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]
M[illegible]texture		[illegible]		[illegible]		[illegible]		12					
[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	25	6					
[illegible]		[illegible]		[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]				[illegible]		28					
[illegible]	1[illegible]			[illegible]	[illegible]	[illegible]	1	[illegible]					

TABLE [illegible]

SUMMARY OF STRUCTURE RATINGS FOR UNIFORM SEGMENTS

	Number of Uniform Segments	Mean	Standard Deviation	Structure Rating Breakdown 0	1	2	3	4	5	6	7	8	9
ASPHALT													
New	722	0.1	0.1	625	93	4							
Microtexture	2061	1.0	1.5	1182	397	176	132	82	68	6	18		
Mixed Texture	4467	1.3	1.5	1723	1241	560	491	312	94	29	16	1	
Macrotexture	1523	1.5	1.5	537	304	291	217	122	40	9	3		
Worn	1213	2.3	1.5	109	312	280	259	137	84	18	10	4	
Porous Friction Course	2939	0.7	1.0	1688	736	269	179	48	17	2			
Chip Seal	567	1.3	1.4	185	187	122	31	9	27	5	1		
Rubberized Chip Seal	329	0.8	1.3	190	97	14	6	2	20				
Slurry Seal	286	1.9	1.4	36	98	59	43	44	6				
ASPHALT WITH SAW CUT GROOVES:													
New	255	0.4	0.8	195	34	10	16						
Microtexture	1991	0.7	1.2	1267	366	197	91	34	10	6	20		
Mixed Texture	3636	0.8	1.1	1762	1072	470	206	82	30	7	7		
Macrotexture	649	1.0	1.2	253	259	56	39	35	6	1			
Worn	121	1.4	0.7	14	46	59	1	1					
CONCRETE:													
Microtexture	352	1.0	1.0	142	121	46	36	7					
Macrotexture	43	0.8	0.5	10	31	2							
Worn	177	1.2	0.8	38	85	41	13						
Burlap Dragged	1501	0.8	1.3	885	273	182	91	31	33	2	1		
Broomed or Brushed	764	0.5	0.7	433	263	58	10						
Wire Combed	500	0.2	0.5	423	62	15							
Wire Tined	755	0.[illegible]	0.5	691	54	2	8						
Float Grooved	479	0.02	0.2	473	2	4							
CONCRETE WITH SAW CUT GROOVES:													
Microtexture	688	1.3	1.4	277	174	83	90	58	6				
Macrotexture	54	1.[illegible]	1.6	6	35	12	1						
Worn	226	1.6	1.0	31	82	57	56						
Burlap Dragged	1992	0.[illegible]	1.2	1503	227	92	113	28	28				
Broomed or Brushed	442	[illegible]	1.0	261	97	[illegible]	21	13					
[illegible]	140	[illegible]	0.[illegible]	116	24								
	28,872			15,[illegible]	6,[illegible]	3,[illegible]	2,[illegible]	1,015	469	85	[illegible]9	5	0

APPENDIX E

Data Summaries for Tables and Figures

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TABLE E-1

DATA SUMMARY FOR TABLES 4 and 6 and
FIGURES 9, 13, 15 and 16

Pavement Types	Uniform With No Rubber			500-Foot Segments With Rubber	
	Mean	Std. Dev.	No. of Cases	Correl. Coeff.	No. of Cases
ASPHALT:					
New	61.9	13.6	665	-.31	57
Microtexture	65.8	9.1	1,695	-.55	366
Mixed Texture	68.4	8.6	3,721	-.69	746
Macrotexture	74.1	7.5	1,332	-.60	191
Worn	74.6	6.7	1,103	-.56	110
Porous Friction Course	77.4	5.6	2,701	-.59	238
Chip Seal	75.1	7.[illegible]	528	--	(39)
Rubberized Chip Seal	73.0	9.9	243	--	(87)
Slurry Seal	70.2	6.9	268	--	(18)
ASPHALT WITH SAW-CUT GROOVES:					
New	73.2	4.4	212	-.52	41
Microtexture	75.0	6.4	1,518	-.42	475
Mixed Texture	73.7	6.5	2,652	-.39	984
Macrotexture	73.5	6.9	493	-.44	156
Worn	71.6	7.4	100	--	(21)
CONCRETE:					
Microtexture	57.9	8.2	295	-.73	57
Macrotexture	66.2	3.1	42	--	(1)
Worn	64.2	8.8	167	--	(10)
Burlap Dragged	57.9	7.2	1,169	-.64	331
Broomed or Brushed	63.3	10.7	414	-.57	225
Wire Combed	68.6	10.6	337	-.41	163
Wire Tined	69.1	7.6	608	-.29	147
Float Grooved	65.6	6.2	415	-.46	64
CONCRETE WITH SAW-CUT GROOVES:					
Microtexture	71.1	7.7	551	-.54	137
Macrotexture	69.7	5.3	44	--	(10)
Worn	72.0	4.3	162	--	(64)
Burlap Dragged	73.7	5.8	1,469	-.55	523
Broomed or Brushed	69.2	6.0	315	-.33	123
Wire Tined	73.8	3.9	105	--	(35)
TOTAL			23,323		5,419

[illegible]

[illegible] corrected for [illegible] ... [illegible] for regression [illegible] ...

[illegible] ... use all [illegible] ... data [illegible]

[illegible] data for [illegible] and [illegible] improved types. [illegible] data [illegible]

[illegible] in parentheses.

[illegible]

TABLE E-2

DATA SUMMARY FOR TABLE 5 and FIGURE 10

	Center Spots with No Rubber					
	Ungrooved			Saw-Cut Grooved		
Pavement Type	Mean	Std. Dev.	No. of Cases	Mean	Std. Dev.	No. of Cases
ASPHALT:						
New	12.5	8.8	107	15.3	6.7	14
Microtexture	14.2	5.6	302	12.7	5.7	159
Mixed Texture	19.3	8.2	559	15.9	6.4	250
Macrotexture	27.7	11.4	241	23.3	6.4	47
Worn	35.0	15.9	193	24.7	9.3	12
Porous Friction Course	48.5	16.6	342	--	--	--
Chip Seal	24 7	9.9	83	--	--	--
Rubberized Chip Seal	39.9	26.3	26	--	--	--
Slurry Seal	19.0	8.7	60	--	--	--
CONCRETE:						
Microtexture	12.4	4.4	48	11.0	1.7	40
Macrotexture	16.5	4.1	6	12.0	4.5	4
Worn	12.8	2.9	22	12.8	4.4	17
Burlap Dragged	13.9	6.7	136	11.9	4.2	122
Broomed or Brushed	14.5	8.5	72	10.5	5.5	19
Wire Combed	18.0	6.8	28	--	--	--
Wire Tined	22.2	13.7	91	20.9	9.6	10
Float Grooved	12.5	6.7	39	--	--	--
TOTAL CASES			2,355			694

NOTES:
1. Table 5 - uses all data.
2. Figure 10 - uses all data in first column ("ungrooved").
3. "Center spots" - located 10 feet from runway centerline; other spot data include "side spots" (near runway edge) and center spots with rubber.

TABLE E-3

DATA SUMMARY FOR FIGURE 11

Curve	Correl. Coeff.	Parameter	Mean	Standard Deviation	Number of Center Spots With No Rubber
ASPHALT	.56	Wet Mu Value	70.9	9.7	1,896
		$\log_e$ (Texture)	3.10	0.60	1,896
CONCRETE	.33	Wet Mu Value	62.4	10.3	397
		$\log_e$ (Texture)	2.64	0.48	397
TOTAL CASES					2,293

NOTES:

1. Texture has units of inches x .001 (e.g., actual 0.0120 inches expressed as 12.0).

2. Asphalt - includes ungrooved types as follows: new, microtexture, mixed texture, macrotexture, worn, porous friction course, chip seal, rubberized chip seal, and slurry seal.

3. Concrete - includes ungrooved types as follows: microtexture, macrotexture, worn, burlap dragged, broomed or brushed, wire combed, wire tined and belt finished.

4. Friction ("wet Mu value") data - read directly from Mu-Meter strip charts for "center spot" locations; some missing friction data result in smaller number of cases here than found by totaling individual pavement types.

TABLE E-4

DATA SUMMARY FOR FIGURE 17

Curve	Inter-cept	Slope	Std. Error of Slope	Correl. Coeff.	Parameter	Mean	Std. Dev.	No. of Cases
ASPHALT	0.23	0.00083	+ 0.00007	.74	Average Rubber	1.0	[illegible].9	106
					Annual Landings	957	1,728	[illegible]
GROOVED ASPHALT	0.76	0.00041	+ 0.00007	.41	Average Rubber	1.2	1.4	[illegible]
					Annual Landings	1,175	[illegible]	[illegible]
CONCRETE	0.52	0.00047	± 0.00008	.77	Average Rubber	1.1	1.7	26
					Annual Landings	1,175	2,738	26
TEXTURED CONCRETE	0.96	0.00013	± 0.00008	.22	Average Rubber	1.3	1.5	50
					Annual Landings	2,694	2,540	50
GROOVED CONCRETE	0.88	0.00013	± 0.00009	.17	Average Rubber	1.0	1.4	77
					Annual Landings	1,312	1,869	77
TOTAL CASES								440

NOTES:

1. Cases restricted to uncleaned runway ends with annual landings greater than 250 million pounds per year, known pavement age, and ability to be classified as "asphalt", "ground asphalt", etc.
2. Average rubber - units of rubber accumulation rating (0-9 scale) as 2000-foot average for runway end.
3. Annual landings - millions of pounds per year for runway end.
4. Curves represent the following pavement types:

AD-A097 334 HICKOK (E A) AND ASSOCIATES INC WAYZATA MN F/G 1/5
NATIONAL RUNWAY FRICTION MEASUREMENT PROGRAM.(U)
DEC 80 J R MACLENNAN, N C WENCK DOT-FA78WA-4242
UNCLASSIFIED FAA-AAS-80-1 NL

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TABLE E-5

DATA SUMMARY FOR TABLE 7 AND FIGURE 18

Curve or Pavement Class	Correl. Coeff.	Parameter	Mean	Standard Deviation	Number of Cases
ASPHALT	.35	Max. Rubber	3.1	2.4	33
		Cum. Landings	410	677	33
GROOVED ASPHALT	.30	Max. Rubber	3.0	2.0	76
		Cum. Landings	1,429	1,783	76
CONCRETE	.71	Max. Rubber	2.7	2.4	28
		Cum. Landings	811	1,758	28
GROOVED CONCRETE	.57	Max. Rubber	3.3	2.3	91
		Cum. Landings	1,741	2,405	91
TOTAL CASES					228

NOTES:

1. Cases restricted to runway ends with record of cleaning during program or within one year prior to first testing and with ability to be classified as "asphalt", "grooved asphalt", etc.

2. Maximum rubber - units of rubber accumulation (0-9 scale) as maximum observed 500-foot segment for runway end.

3. Cumulative landings - millions of pounds since rubber cleaning date for runway end.

4. Curves, or pavement classes, represent runway ends having predominant pavement type or types in the listed categories.

TABLE E-6

DATA SUMMARY FOR FIGURE 19

PART A - FRICTION RELATED TO RUBBER ACCUMULATION

Pavement Type	Correlation Coefficient	No. of Uniform 500-Ft Segments With Rubber
ASPHALT:		
Microtexture	-.55	366
Mixed Texture	-.69	746
Macrotexture	-.60	191
Worn	-.56	110
ASPHALT WITH SAW-CUT GROOVES:		
New	-.53	43
Microtexture	-.42	473
Mixed Texture	-.39	984
Macrotexture	-.44	156
CONCRETE:		
Microtexture	-.73	57
Burlap Dragged	-.64	331
Broomed or Brushed	-.57	225
Wire Combed	-.41	163
Wire Tined	-.29	147
CONCRETE WITH SAW-CUT GROOVES:		
Microtexture	-.54	137
Burlap Dragged	-.55	523
Broomed or Brushed	-.33	123
TOTAL CASES		4,775

NOTES:

1. This represents subset of data from Table 6 (excludes new asphalt, porous friction course, and float grooved concrete).

2. Correlation coefficient - shown is simple correlation between rubber and friction data.

3. Figure 19 - based on combined results of Table 6 (see above) and Table 7 (see below).

TABLE E-6 (continued)

PART B - RUBBER RELATED TO CUMULATIVE LANDINGS

Pavement Type	Correlation Coefficient	No. of Uniform 500-Ft Segments With Rubber
ASPHALT	.35	33
GROOVED ASPHALT	.30	76
CONCRETE	.71	28
GROOVED CONCRETE	.5	91
TOTAL CASES (Runway Ends		228

NOTES: 4. This represents data from Table 7.

5. Correlation coefficient - shown is simple correlation between maximum 500-foot segment rubber and cumulative landings since rubber cleaning date for runway end.

APPENDIX F

Photographs of Pavement Types

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APPENDIX F - PHOTOGRAPHS OF PAVEMENT TYPES

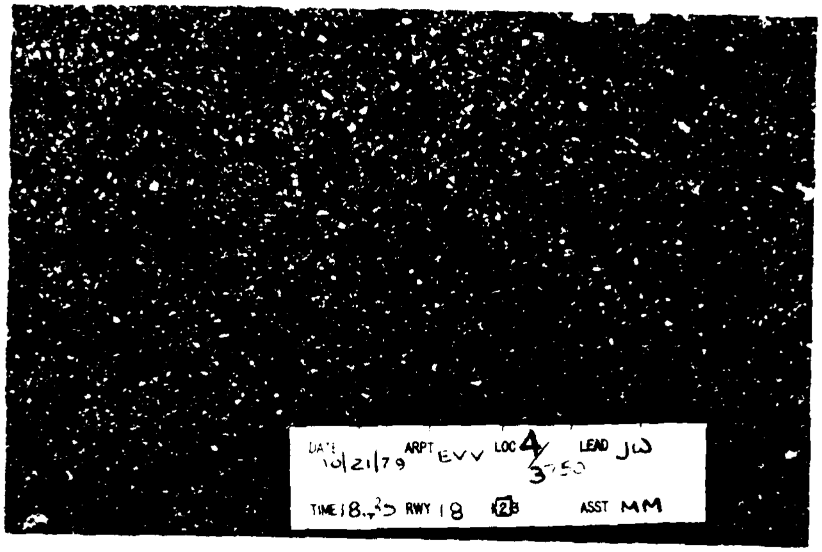

FIGURE F-1. SLURRY SEAL COAT

FIGURE F-2. NEW ASPHALT

FIGURE F-3. MICROTEXTURE ASPHALT

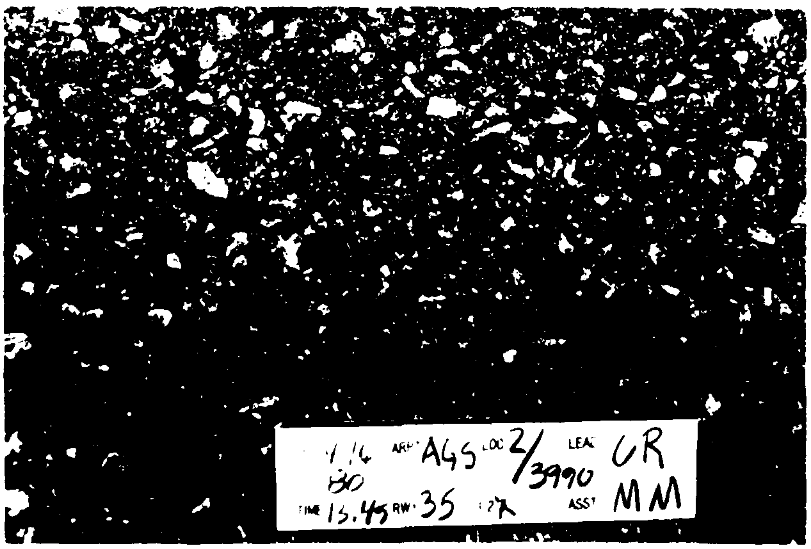

FIGURE F-4. MIXED-TEXTURE ASPHALT

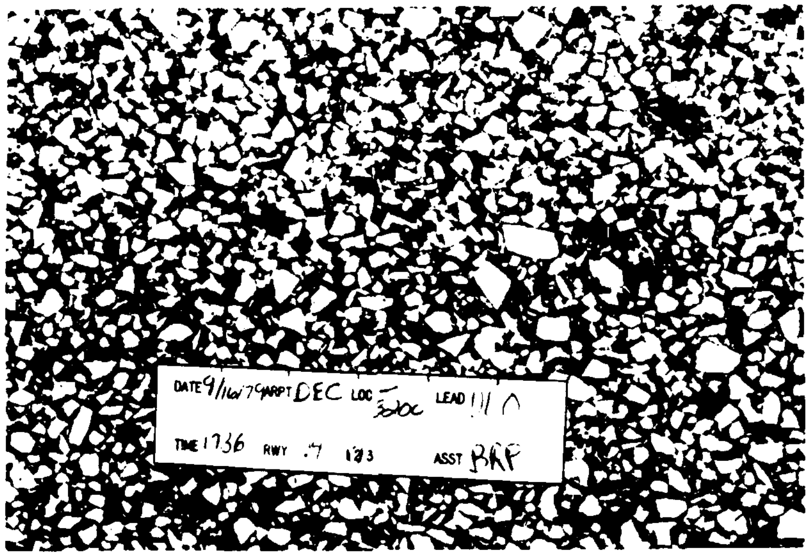

FIGURE F-5. MACROTEXTURE ASPHALT

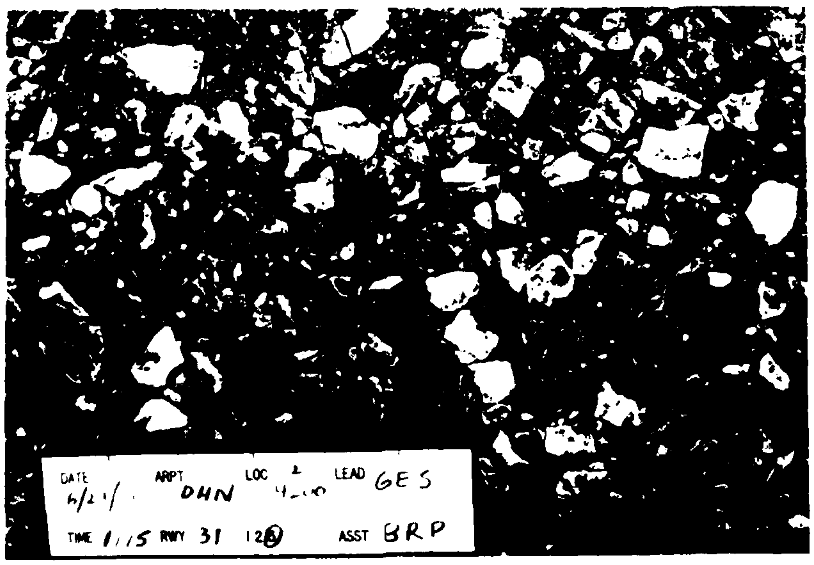

FIGURE F-6. WORN SURFACE ASPHALT

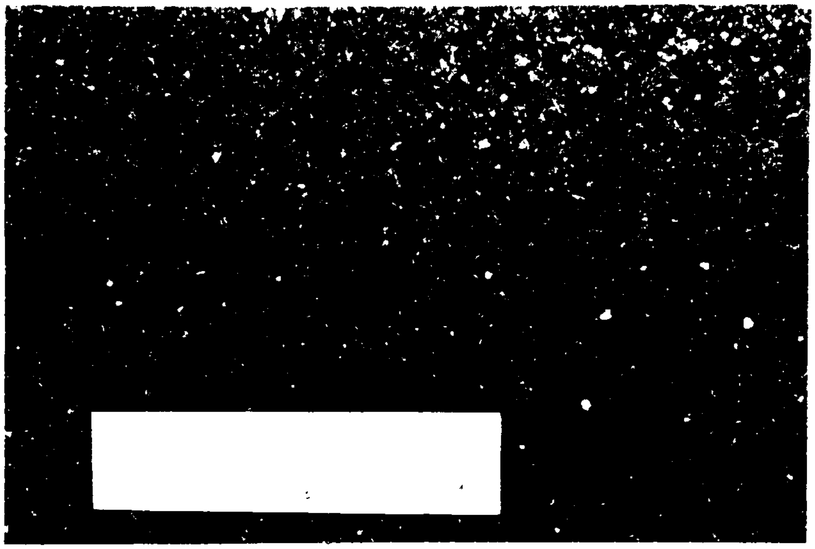

FIGURE F-7. POROUS FRICTION COURSE

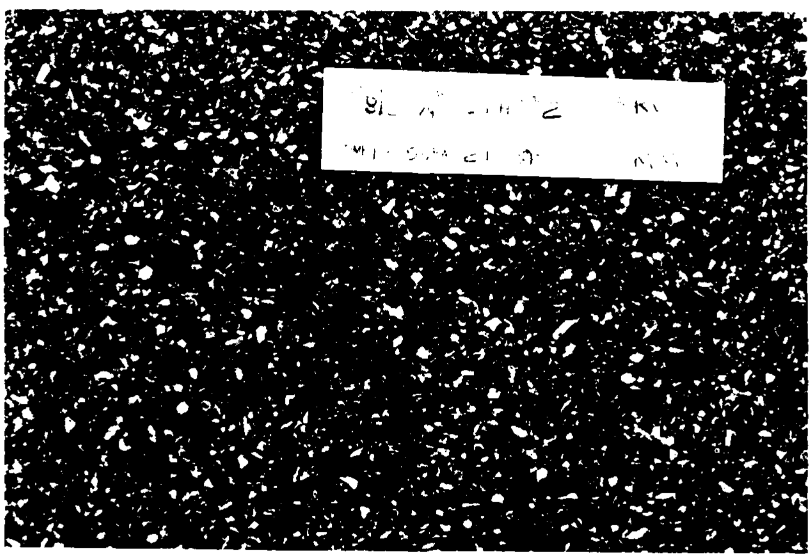

FIGURE F-8. CHIP SEAL

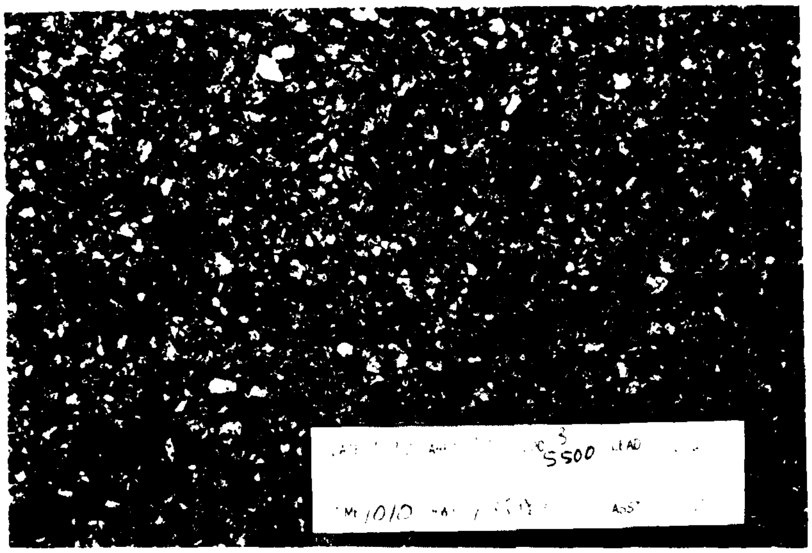

FIGURE F-9. RUBBERIZED CHIP SEAL

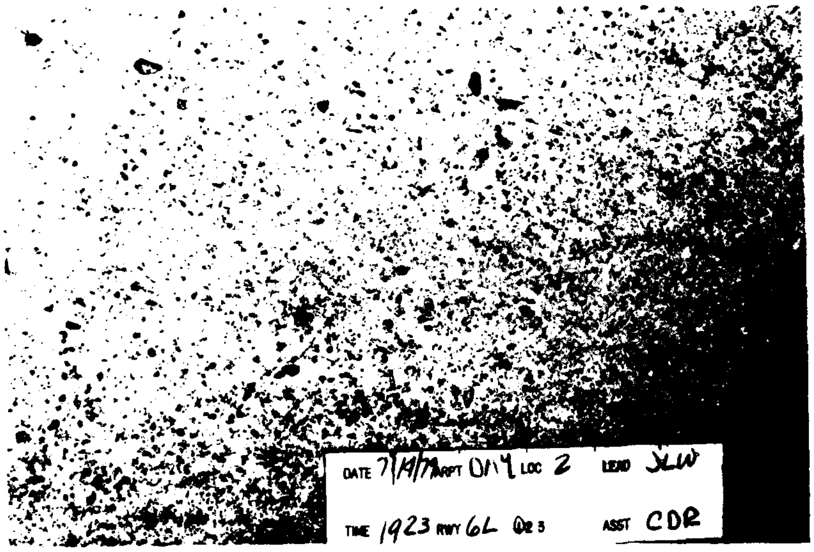

FIGURE F-10. MICROTEXTURE CONCRETE

FIGURE F-11. MACROTEXTURE CONCRETE

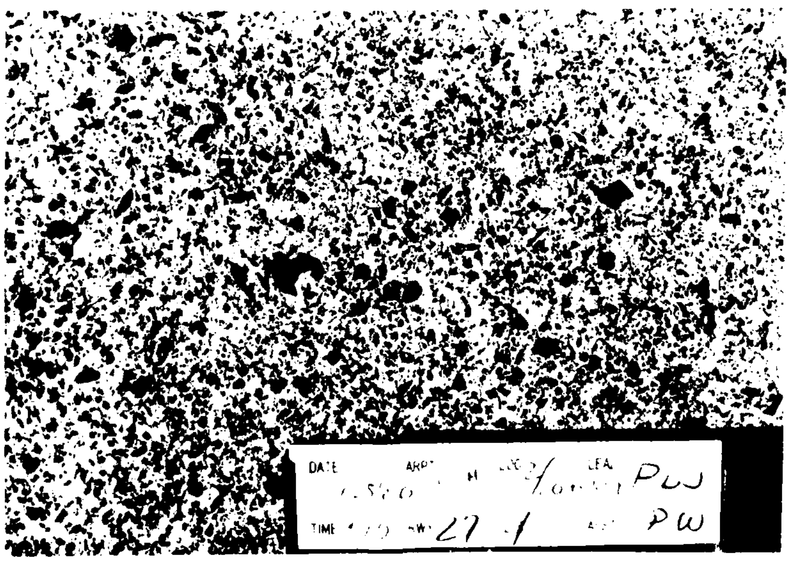

FIGURE F-12. WORN SURFACE CONCRETE

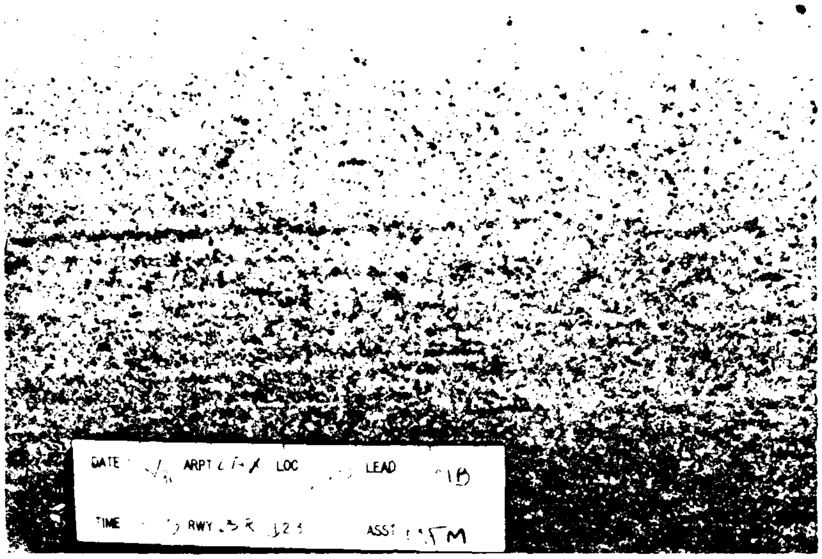

FIGURE F-13. BURLAP DRAGGED CONCRETE

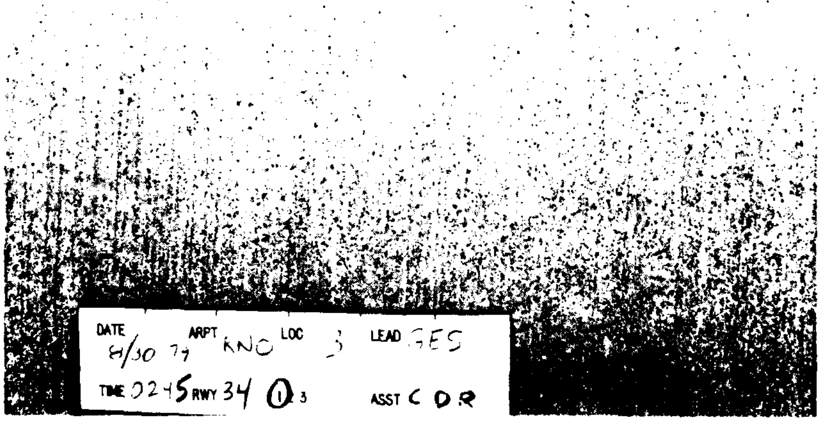

FIGURE F-14. BROOMED OR BRUSHED CONCRETE

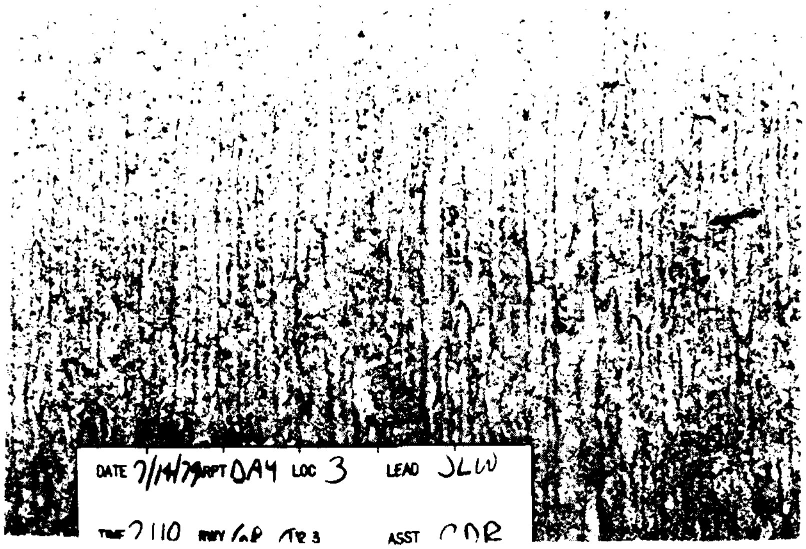

FIGURE F-15. WIRE COMBED CONCRETE

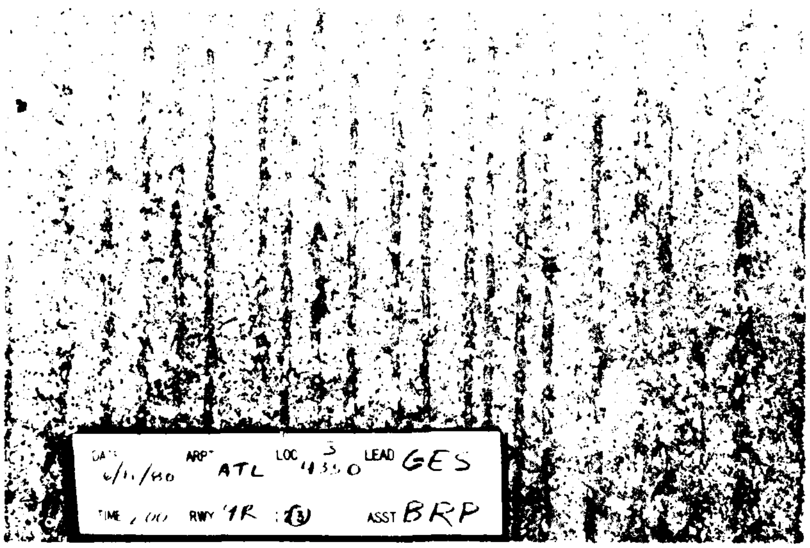

FIGURE F-16. WIRE TINED CONCRETE

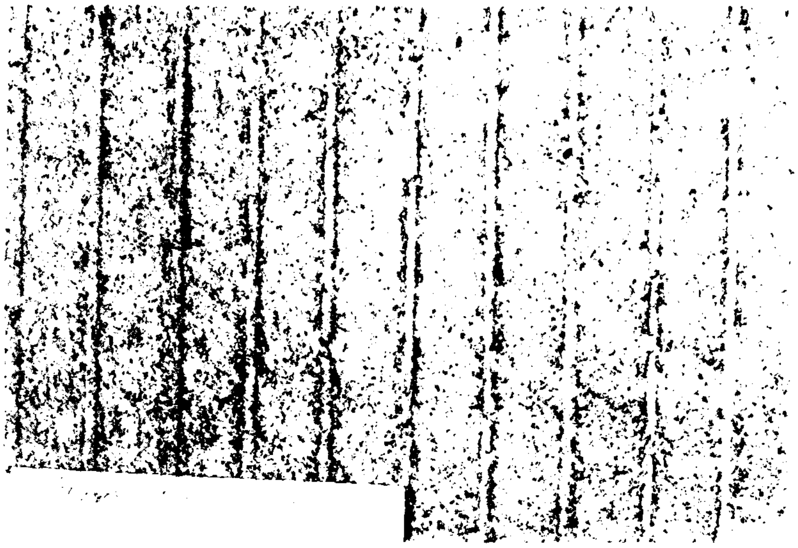

FIGURE F-17. FLOAT GROOVED CONCRETE

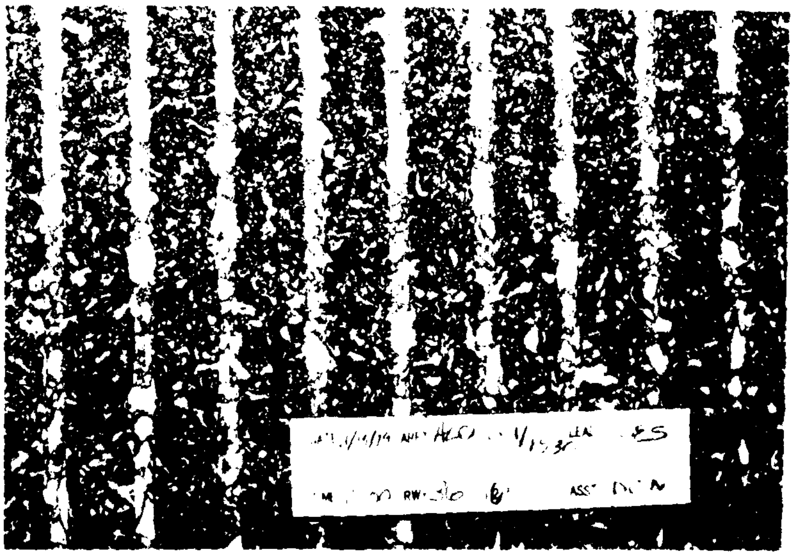

FIGURE F-18. MICROTEXTURE ASPHALT WITH SAW CUT GROOVES

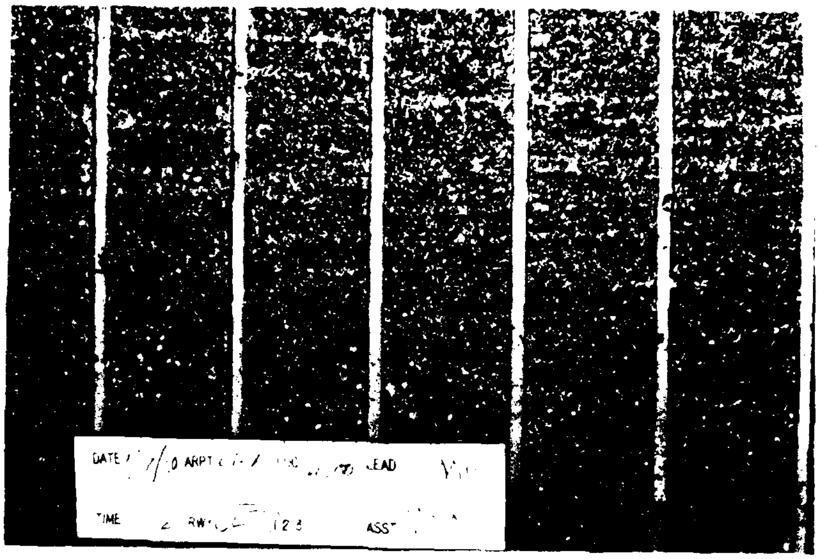

FIGURE F-19. BURLAP DRAGGED CONCRETE WITH SAW CUT GROOVES

APPENDIX G

SUMMARY OF RESULTS OF MU-METER VARIABILITY STUDY

TEST PROCEDURE

Variability tests were performed by the FAA's Technical Center using two Mu-Meters run continuously through the 500-foot concrete pavement section for ten runs with self-watering systems operating. After completing ten runs, water tanks were refilled and the next ten runs were conducted. The data were obtained from the Mu graph chart. Mu averages were estimated for each 100-foot segment of the 500-foot averages for each Mu-Meter were obtained by totaling the Mu averages for each 100-foot segment and dividinj by five.

SUMMARY OF RESULTS

	ML 361	ML 364	ML 365	ML 366*	ML 378	ML 383
Mean of 20 Measurements	56.62	54.88	57.91	58.89	56.23	55.13
Probable Error from Mean of All Readings	1.40	1.47	1.62	2.00	0.93	1.36
Probable Error from the Mean of Each Device	1.40	1.02	1.24	0.94	0.92	1.04

*Ten measurements performed with this equipment.

CONCLUSIONS

The results of the above analysis concur with the manufacturer's findings that the acceptable variability of the Mu-Meter is within ± 2 Mu values.

APPENDIX H

Hydrologic Study

MEMORANDUM

BY: John Erdmann
DATE: February 15, 1979
SUBJECT: FAA National Runway Friction Measurement Program
Equivalence of Rainfall Intensity to Mu-Meter Water Depth

SUMMARY AND CONCLUSIONS

In the subject program, wet friction measurements with a Mu-Meter use a controlled water depth of 0.04 inches (or 0.02 inches for measurements made earlier in the program). The question naturally arises, what is the rainfall intensity equivalent to the controlled water depth used in the measurements? By investigating and reconciling two different approaches to this question, as subsequently described, the results presented in Table 1 were achieved.

TABLE 1. - Equivalent Rainfall Intensity for Wet Friction Measurements*

Average Texture Depth Inches	Equivalent Rainfall Intensity, Inches Per Hour: Water Depth 0.02 Inches	Equivalent Rainfall Intensity, Inches Per Hour: Water Depth 0.04 Inches
0.01	0.44	1.40
$\boxed{0.02}$	$\boxed{0.40}$	1.26
0.03	0.37	1.18
0.04	0.36	$\boxed{1.13}$
0.05	0.34	1.09
0.06	0.33	1.06
0.07	0.33	1.03
0.08	0.32	1.01
0.09	0.31	0.99
0.10	0.31	0.98

WATER DEPTH ABOVE ASPERITIES

WATER DEPTH BELOW ASPERITIES

*Assuming distance from centerline 10 feet and transverse slope 1.5 percent.

Thus far in the Program, average texture depth has been less than 0.05 inches in the great majority of cases.

The "Federal Meteorological Handbook No. 1" (2nd edition, January, 1979) classifies rainfall as follows:

Rainfall Intensity, Inches Per Hour	Classification
Trace - 0.1	Light rain
0.1 - 0.3	Moderate rain
Greater than 0.3	Heavy rain

Thus, in all cases shown in Table 1, equivalent rainfall intensity falls in the "heavy rain" category.

The remainder of this memorandum documents the results presented in Table 1.

GENERAL BACKGROUND

Equivalence between rainfall intensity and water depth on pavement has been investigated by the Texas Transportation Institute for the special case in which water depth exactly equals average texture depth. An empirical equation was developed to relate equivalent rainfall intensity to average texture depth, transverse slope and distance from pavement crown.

An alternative approach is based on Manning's equation for flow. Both approaches were investigated and they were found to be similar in theory. However, each approach has a distinct advantage. The first approach (Texas Transportation Institute) is precisely calibrated for the question at hand, but is applicable only when texture depth exactly equals water depth. The second approach (Manning's) is applicable when texture depth differs from water depth, but it requires calibration of an additional variable (Manning's n, related to pavement "roughness") for the question at hand.

The two approaches were reconciled so as to retain the advantages of each.

NOMENCLATURE

RI = rainfall intensity (in./hr.);

T = average texture depth (in.);

L = distance from pavement crown, i.e. runway centerline, to location of interest (ft.);

S = transverse slope (ft./ft.);

d = depth of water (in.);

v = velocity of flow away from pavement crown (ft./sec.); and

n = Manning's n (dimensionless).

FIRST APPROACH - TEXAS TRANSPORTATION INSTITUTE

Mr. Morrow of the FAA communicated the following equation, developed by the Texas Transportation Institute, for the rainfall intensity required to fill a given texture depth exactly:

$$RI\ (d=T) = 1.543 \times 10^4 \times \left\{\frac{T^{.89} \times S^{.42}}{L^{.43}}\right\}^{1.695} \qquad (1)$$

The notation RI(d=T) signifies that water depth must equal texture depth for this equation to be applicable.

For the usual case where L=10 feet from centerline and slope S=0.015, Eq. 1 gives the following results:

d or T, inches	RI(d=T), inches/hour
.02	.40
.04	1.13
.06	2.08
.08	3.31
.10	4.49

Thus, for example, where water depth and average texture depth both equal 0.04 inches, the equivalent rainfall intensity is 1.13 inches per hour.

SECOND APPROACH - MANNING'S EQUATION

A water balance requires that the rainfall between the centerline and a point at distance L from the centerline must equal the rate of flow over the pavement surface away from the centerline, at the distance L. This implies the following equation (which includes unit conversions):

$$\frac{RI \times L}{12 \times 3600} = \left\{\frac{d}{12}\right\} \times v \qquad (2)$$

According to Manning's equation, the velocity away from the centerline, v, is related to the hydraulic radius (equal in the case of a 'v' channel to $d/2^{.5}$), transverse slope S, and factor n (dependent on roughness) as follows:

$$v = \frac{1.49}{n} \times S^{1/2} \times \left\{\frac{d}{12 \times 2^{1/2}}\right\}^{2/3} \qquad (3)$$

Substituting Eq. 3 into Eq. 2 and solving for RI yields

$$RI = 812 \times \left\{\frac{S^{1/2} \times d^{5/3}}{L \times n}\right\} \qquad (4)$$

A reasonable value for Manning's n is .04. This assumption, with the usual values L=10 feet and S=.015, results in an estimated rainfall intensity of 1.16 inches per hour for a water depth of 0.04 inches. Agreement with the estimate by Eq. 1 (1.13 inches per hour) is achieved by increasing Manning's n to .041.

RECONCILING THE TWO APPROACHES

Eq. 4 can be calibrated to Eq. 1 by solving for the values of Manning's n required to make the two equations agree in those special cases where texture depth equals water depth as follows:

d or T, inches	RI(d=T), inches/hour	Manning's n
.02	.40	.037
.04	1.13	.041
.06	2.08	.044
.08	3.21	.046
.10	4.49	.048

By plotting n versus T on logarithmic paper, these two variables are found to fit the following relation:

$$n = 0.06969 \times T^{0.1664} \qquad (5)$$

Substituting this result in Eq. 4 then gives

$$RI = 1.165 \times 10^4 \times \left\{\frac{S^{1/2} \times d^{5/3}}{L \times T^{0.1664}}\right\} \qquad (6)$$

For the usual case where S = .015 and L = 10 feet,

$$RI = 142.7 \times d^{5/3} / T^{0.1664} \qquad (7)$$

Eq. 7 then represents Eq. 4 "calibrated to" Eq. 1.

The observation that Eq. 1, upon simplification, has the same general form as Eq. 4 suggests one further refinement. Further, with S=.015 and L=10 feet, Eq. 1 becomes

$$RI(d=T) = 144.9 \times T^{1.50855} \qquad (8)$$

Eq. 7 can then be made to agree more exactly with Eqs. 8 and 1 by adjusting the coefficient and the exponent of T as follows:

$$\boxed{RI = 144.9 \times d^{5/3} / T^{0.1581}} \qquad (9)$$

Eq. 9 might be said to represent Eq. 1 "modified according to" Manning's equation.

Eq. 9 is the final result of this investigation and is the basis for the equivalent rainfall intensities in Table 1. Note that this result specifically assumes a transverse slope of 1.5 percent and a distance from runway centerline of 10 feet. These represent usual conditions for the Mu-Meter wet friction measurements, thus equivalent rainfall intensity can in most cases be found using either Eq. 9 or Table 1.

The .04 inches deposited in front of the measuring wheels will just fill the texture when it has a mean depth of .040 inches. When the same amount of water is applied to a runway with a mean texture depth of .020 inches, .02 inches will be above the texture and will flow more freely. The equivalent rainfall rates required to achieve a total water depth of .04 inches 10 feet from the centerline of a runway with a transverse slope of 1.5 percent are 1.1 and 1.3 inches per hour for mean textures of .040 and .020 inches, respectively.

The nine FAA regional office locations have statistically predicted rainfall intensities that will equal or exceed these rates for different lengths of time. The following table shows the duration, in minutes, of storms with return frequencies of 2 years and 10 years, having intensities exceeding the Mu-Meter self-watering rate for each location, for the two textures.

Location	Return Frequency			
	2 Years		10 Years	
	1.1 in./hr.	1.3 in./hr.	1.1 in./hr.	1.3 in./hr.
Boston	50	40	105	85
New York	75	60	165	130
Atlanta	100	85	180	150
Chicago	80	65	130	115
Kansas City	95	70	210	170
Fort Worth	105	90	220	180
Denver	30	23	75	60
Seattle	6	4	19	15
Los Angeles	18	14	52	30

APPENDIX I

Report of Inventions

APPENDIX I - REPORT OF INVENTIONS

The work performed under this contract, while leading to no new invention, has led to several innovative concepts on the use of Mu-Meter surface friction measurements for design and maintenance of nonslippery surfaces at United States airports. This constitutes the first nationwide body of data on runway surface friction characteristics, as well as other surface conditions. The data were used to analyze the effect of pavement type and texture, grooves, rubber accumulation, rubber removal, climate and traffic on surface friction characteristics and application of those characteristics to maintenance plans.

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